INTERPRETATION OF 2D COMPUTER TOMOGRAPHY AND 3D RECONSTRUCTION AND ITS ROLE IN THE DIAGNOSIS OF FACIAL BONE FRACTURES

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CERTIFICATE

This is to certify that the dissertation entitled **"INTERPRETATION OF 2D COMPUTER TOMOGRAPHY AND 3D RECONSTRUCTION AND ITS ROLE IN THE DIAGNOSIS OF FACIAL BONE FRACTURES"** is the bonafide original work done by **Dr. Jeeth Isaac Jacob.** This study was undertaken at the **Christian Medical College Hospital, Vellore** from the year August 2006 – August 2008 under my direct guidance and supervision, in partial fulfillment of the requirement for the award of the **M.Ch** Branch III (**Plastic Surgery**) degree of the **Tamilnadu Dr.M.G.R. Medical University.**

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CONTENTS

INTRODUCTION

Facial injuries are clinically significant because they are often complex in nature and may have serious functional and cosmetic sequelae. As a result of this accurate diagnostic evaluation is of prime importance. Modern imaging techniques especially the computerized tomography has revolutionized the diagnostic capabilities in this modern era.

For many years both surgeons and physicians relied on 2 dimensional radiography of the facial skeleton to evaluate facial injuries. However such radiographs were relatively difficult to interpret because of the interposition of bony landmarks and defects.

In the 1970`s the multi-slice 2D CT became more widespread and was better able to represent the defects in the facial skeleton. CT`s accurate representation of facial fractures and their spacial relationships facilitates surgical exploration, fracture reduction and the selection and contouring of rigid plates.

As a result of this the CT has decreased the complications resulting from delays in diagnosis and treatment including malunion, non-union, and other functional and aesthetic deficits that may require revision surgery.

Surgeons generally need to make their own evaluation of the degree of skeletal disruption revealed by the imaging studies when planning initial treatment of facial fractures.

Recently advances in computer software algorithms have permitted three-dimensional (3D) reconstructions of the facial skeleton from 2D CT images. These 3D images may further facilitate the diagnosis and treatment of facial injuries and numerous authors have suggested that such 3D images may prove superior to 2D CT for pre-surgical planning in complex trauma.

This study compares the efficacy of 3D CT over 2D CT and to determine whether any additional information would have a bearing in the management plan.

AIM OF THE STUDY

This is prospective study of 35 patients who were diagnosed to have facial bone fractures and had undergone CT scanning for the same.

The study was designed to find out the efficacy of 3D CT and used 3 main criteria, which include

1. To determine various fracture sites on 2D CT

2. To determine the various fracture sites on 3D CT

3. To determine whether any additional information was obtained by 3D CT that was missed in 2D CT there by making 3D CT a mandatory investigation for facial bone fractures.

REVIEW OF LITERATURE

HISTORY OF FACIAL BONE FRACTURES

Diagnosis and treatment planning of abnormalities of the skull especially of the midface following trauma is limited using standard radiography. This is due to less than optimal image resolution, lack of dimensional accuracy, image distortion, and the presence of superimposed structures, edema, and hemorrhage.[1] Therefore accurate imaging of maxillofacial injury is essential for evaluation of acute trauma.

Several imaging modalities are used in the diagnosis of maxillofacial injuries including plain films, conventional tomography and computerized tomography. Post processing of CT scans to form 2D multiplanar reconstructions and 3D reconstruction is often done.

Before the advent of CT scanning the diagnosis of facial fractures was routinely based on clinical investigation and plain radiography. Orthopantomography (OPG), a posteroanterior mandibular view , occipitomental views of different angulation (300 and 450 views) and a submental vertex lateral view for nasal fractures were so common in the initial diagnosis of facial fractures that they could almost be called as part of the protocol for initial assessement.

Although these radiographs can demonstrate the presence of fractures of the midface in selected cases (e.g., zygomatic fractures), they seem to only be a first step in the documentation and predict the need for additional CT examinations for the confirmation of the initial diagnosis.

The clinical investigation begins with conventional plane film radiography. However plain films have inadequate contrast between bone and soft tissue components to detect, describe and classify all the fractures which may be present.

Because of the superimposition of bony structures on plain radiographs, interpretation of facial injury can be intimidating and inaccurate. Helical CT with two- and three-dimensional reformations greatly simplifies interpretation, is highly accurate for diagnosing fractures and soft tissue injuries, and is more accurate than plain radiographs for many fractures. Helical CT is also accurate in assessing which areas of facial injury are stable or unstable for planning corrective surgery and in determining the degree of displacement or rotation of major bony fragments. Helical CT has been shown to be faster and to produce planar and three-dimensional reformations with less motion artifact than conventional CT in the assessment of facial trauma. The diagnostic value of three-dimensional images has been studied, and three-dimensional images have been shown to add significantly in the evaluation of severe facial trauma in 29% of patients. Three-dimensional imaging appears superior in localization of complex fractures involving multiple planes, in perception of fracture displacement, and in assessment of facial symmetry. Three-dimensional imaging has been used for fabrication of bone grafts in complex facial restoration.

CT and 3D reconstruction have been used for craniofacial trauma evaluation. Several previous studies compared the diagnostic utility of these two modalities. De Marino et al concluded that the interpretation and detailed assessment of 2D CT sections was significantly limited without prior viewing of the 3D reconstruction.[2] CT has been shown to be more sensitive for the detection of fractures.[3] Because of the complex anatomy of the facial skeleton, a comprehensive CT evaluation in cases of severe trauma may require scanning in both transaxial and coronal plane (Johnson, 1984) or thin section transaxial imaging with multiplanar reformatting.[4]

Optimal surgical correction of facial injuries requires an accurate three-dimensional appreciation of the resulting disordered facial anatomy. Deriving this information from a large number of two-dimensional images can be difficult and can be achieved with variable degrees of success depending on the observer`s experience of CT. Three-dimensional (3D) reformatting of CT data is being undertaken in a variety of centers these days in an attempt to overcome this problem.

Three-dimensional computed tomography is gaining acceptance in various fields of maxillofacial surgery. Restoration of facial esthetics and function (e.g., mastication, symmetrical movement of eyeballs and their optimal position to avoid double vision and speech) after facial trauma is an essential aim to the plastic surgeon. The primary definitive treatment of open reduction and internal fixation using mini and microplates and, if necessary, immediate bone grafting is now the standard of care, offering the optimal treatment of facial fractures.

Successful fracture treatment depends on precise clinical and radiological examinations to conceptualize the overall injury and to establish a correct diagnosis. Failure to recognize, and the resultant mistreatment, of facial fractures is an important cause for later cosmetic and functional complications, which are difficult or even impossible to correct at a secondary stage.

Developments in 3D reconstruction using software helps reconstruction of complex anatomic parts. This provides the clinician with a theretofore unavailable global image of the facial anatomy as a preoperative or postoperative diagnostic tool.[5]

The 3D reconstruction may further facilitate the diagnosis and treatment of facial injuries and many authors have suggested that such 3D images may prove superior to 2D CT for presurgical planning in complex facial trauma.[6]

FIVE REGIONS OF THE FACE

To simplify the diagnostic task, the face may be thought of as five regions that may fracture as an entity or in combination with adjacent regions. These regions represent areas of focus for presurgical planning and are as follows: (1) nasal, (2) orbital, (3) zygomatic, (4) maxillary, and (5) mandibular.[14]

These regions and the supporting facial buttresses are easy to analyze on CT and are involved with characteristic fractures and fracture patterns. All but the mandibular region share bony surfaces and a single fracture line may involve more than one region. The nasal region includes the nasal bones and soft tissues, frontal processes of maxilla, lacrimal bones, cartilaginous and bony nasal septum, and the ethmoid sinuses. The conically shaped orbital region consists of the roof, medial and lateral walls, floor, and orbital rim as well as the intraorbital soft tissues. The zygomatic region consists of the zygoma and parts of the four other bones to which the zygoma attaches: (1) the maxillary, (2) sphenoid, (3) temporal, and (4) frontal bones. The alveolar process of the maxilla, palatine process of the maxilla, and palatine bone constitute the maxillary region of the face. Lastly, the mandible and temporomandibular joints make up the mandibular region.

A given bone may not be confined entirely within the region bearing its name. The maxilla, for example, forms part of the orbital floor and its frontal process forms part of the nasal region. The regions of the face are held in place by portions of the struts and the buttresses of the face. For example, the maxillary region is supported by the walls of the maxillary sinuses, the nasal septum, and the pterygoid plates. If the maxillary region were fractured and separated from the rest of the face, fractures must be seen involving the walls of the maxillary sinuses, the bony nasal septum, and the pterygoid plates (i.e., a classic Le Fort I fracture). The zygomatic region is supported by three thicker pieces of bone: (1) the lateral orbital rim; (2) the inferior orbital rim; and (3) the zygomatic arch, all of which must be fractured if the body of the zygoma is to be separated from the rest of the face. Such a fracture also has to involve the thinner bones to which the zygoma contributes and to which it is attached. These thinner bones form the lateral wall of the orbit, the floor of the orbit, and the lateral and anterior walls of the maxillary sinus. The nasal region is supported by the medial orbital rim and medial aspect of the inferior orbital rim as well as by its attachments to the frontal bone. The nasal region shares with the orbit the medial orbital wall. The orbital region as defined by the conically shaped space does not separate from the rest of the face as the zygomatic and maxillary regions can with injury. The strongest bones supporting this space are those forming the orbital rim.

The volume of the orbit, however, is also critically dependent on the smaller and thinner bones forming its walls. The mandible is the only bone of the face that does not have a suture with other facial bones. As a result, it is self-contained and does not share borders with the rest of the face. It is supported by its attaching muscles and by the glenoid fossa at the temporomandibular joint.

TYPES OF FACIAL FRACTURES AND SOFT TISSUE INJURIES

Before considering the interpretation of facial CT and how thinking in terms of the five regions of the face can greatly simplify this interpretation, it is useful to consider the standard classifications of facial injuries.

Nasal and Naso-orbital-ethmoid Fractures

The nasal region fractures usually are grouped into simple nasal fractures and the more complex naso-orbital-ethmoid (NOE) fractures. The simple nasal fractures involve the nasal bones alone or the nasal bones and the frontal processes of the maxilla. Displacement or angulation may occur inferiorly or laterally. At times, the anterior maxillary spine may also be avulsed and is associated with disruption of the cartilaginous nasal septum.[37] The NOE fractures involve the boundaries shared by the nasal and orbital regions (i.e., the ethmoid sinuses and orbital rim). The NOE fractures involve posterior displacement (telescoping) of the anterior nasal structures into the lacrimal bone (which forms part of the medial orbital rim) and into the ethmoid sinuses. In addition to telescoping, there frequently is lateral displacement of fracture fragments. Critical change in orbital volume and injury to the medial canthal ligament, cribriform plate, nasofrontal duct, and the nasolacrimal duct may occur with the NOE fractures.[38]

Zygomatic Fractures

With a blow to the cheek, the body of the zygoma may be separated from the rest of the face in a fracture pattern known as the zygoma *complex fracture***.** Fractures should be seen involving the three thicker pieces of bone supporting the zygoma; there frequently is separation at the zygomaticofrontal suture (although the fracture line may involve the frontal process of the zygoma instead); the inferior orbital rim is fractured; and there is fracture of the zygomatic arch. The orbital floor is inevitably involved as is the lateral wall of the orbit and the anterior and lateral walls of the maxillary sinus. The lateral wall fracture may extend posteriorly and involve the orbital apex.[37] The body of the zygoma may be displaced medially and posteriorly and may be rotated. The degree of displacement and rotation is important to assess and may be well seen with three-dimensional reformations. If orbital volume is affected by this fracture, reduction of displacement and fixation are necessary.[39] If there are no symptoms or instability, zygomatic fractures may be treated without surgery. In addition to the zygoma complex fracture, the zygomatic arch is vulnerable to isolated fracture by a direct blow**.** There may be medial displacement of a portion of the arch or the arch may be angulated medially through the sites of fracture. By impingement on the temporalis muscle or the coronoid process of the mandible, the displaced arch fracture may interfere with opening and closing of the mouth or may alter dental occlusion.

Orbital Fractures

Although the walls and rim of the orbit are often fractured in conjunction with fractures of adjacent regions, isolated fractures of the orbit may occur. The blow-in fracture, which involves the orbital roof with inferior displacement of fracture fragments into the soft tissues of the orbit, may be seen as an isolated injury but in more than half of cases is associated with frontal sinus or skull fractures.[40] These blow-in fractures may extend posteriorly and involve the orbital apex with potential for injury to the optic nerve. These fractures usually are unilateral, but bilateral blowin fractures may occur rarely. The blow-in fracture with an intact superior orbital rim is felt to be the result of a blow to the frontal bone, which may not fracture but rather transmit the forces to the thinner orbital roof resulting in its buckling downward. If the roof is fractured in conjunction with other fractures that involve a sinus, pneumocephalus may occur. Ocular injuries are seen in 14% to 29% of patients with blow-in fractures.[41] The blow-out fractures may involve either the orbital floor, medial wall, or both**.** CT imaging in both axial and coronal planes is necessary for accurate demonstration of these fractures.[42] The orbital rim is intact by definition if the blow-out designation is used. With blow-out fractures, there is inferior displacement of a portion of the floor into the maxillary sinus or medial displacement of a portion of the medial wall into the ethmoid sinus. With sufficient force the medial blow-out may extend not only through the medial wall but also through the floor of the ethmoid sinus into the nasal cavity. These fractures occur with a blow to the orbit that increases intraorbital pressure sufficiently to break the thinner bone of the floor or medial wall while leaving the orbital rim intact. The blow-out fractures expand orbital volume due to the resulting herniation of orbital fat and possibly extraocular muscle (medial or inferior rectus) through the site of fracture into the adjacent sinus. Entrapment of muscle against the edge of intact orbital wall can occur with limitation of ocular movement. Entrapment is more frequent with smaller fractures, whereas enophthalmos is more frequent with larger fractures. At CT entrapment may be seen as an abrupt kink in the muscle as opposed to a smooth prolapse through the site of release of entrapped muscles and restoration of orbital volume requires surgical repair. It is thus important to visualize the size of these blow-out fractures and the point at which intact bone exists for stabilization of prosthetic material, which must be placed to restore the orbital wall. With blow-out fractures of the floor it is especially important to know preoperatively whether the fracture extends to involve the upper posterior wall of the maxillary sinus. If this portion of the sinus is involved, restoration of orbital volume is more difficult. The oblique sagittal reformation parallel to the inferior rectus is useful to assess large blow-out fractures and the relationship of the inferior rectus to the intact bone of the orbital floor. Fractures of the orbital rim may occur with a narrowly focused blow or a blow of more force than that resulting in a blow-out fracture. These fractures may extend into the adjacent orbital wall for varying distances. For example, an inferior rim fracture may extend into the orbital floor with herniation of orbital contents through the floor fracture. The rim fracture may require surgical plating, especially if there is a free fragment or rim displacement. Because the required surgery is different than repair of the floor alone, fracture of the rim with extension into the floor should not be called a blow-out fracture. If there appears to be a single fracture of the rim, careful search should be made for a second fracture because the orbital rim is a ring-like structure that may fracture in more than one place.

Fractures Involving the Maxillae

Portions of the maxillary bones are involved with NOE, orbital, and zygomatic fractures. There are other midfacial injuries that result in fractures involving part or all of the maxillae and adjacent regions of the face. Le Fort[7] developed the classification that describes many of these fractures. These are easily remembered if one thinks of the physical examination that accompanies each of the classic fracture types. In the Le Fort I fracture, physical examination reveals that the maxillary alveolar bone and hard palate are movable relative to the rest of the face, which remains attached to the skull. For this to occur, there must be fractures of those structures supporting these parts of the maxillae and palatine bones (i.e., fractures are seen of the pterygoid plates, the vertical walls of the maxillary sinuses, and the nasal septum).

In the Le Fort II fracture, physical examination reveals that the maxillary and nasal regions are movable relative to the rest of the face and skull. For this to occur, there must be fractures of those structures supporting the pyramidally shaped maxillary and nasal unit (i.e., fractures are seen of the pterygoid plates and the inferior and medial orbital rims, and there are fractures across the nasal bones or diastases of the nasofrontal sutures. In the Le Fort II injury the connected thinner bones also fracture including the lateral and anterior wall of the maxillary sinuses, the orbital floor, and the medial walls of the orbits. In the Le Fort II, the zygomatic bones remain attached to the skull by the lateral orbital rim and the zygomatic arch. In the Le Fort III fracture, physical examination reveals that the entire upper face (nasal, maxillary, and zygomatic regions) are movable relative to the skull. For this to occur, there must be fractures of those structures attaching the upper face to the skull (i.e., fractures are seen of the pterygoid plates, the zygomatic arches, the lateral rims of the orbit, the medial orbital rims, and fractures near or diastases of the nasofrontal sutures). The thinner bones that must be fractured include the lateral walls of the orbits, orbital floors, and medial walls of the orbits. The area that is mobile on physical examination in all Le Fort fractures is the maxillary region; thus, the key to the presence of one of the Le Fort fractures is fracture of the pterygoid plates, which is easily seen at CT. Occasionally, Le Fort fractures exist without facial mobility on physical examination.[43] These fractures may present clinically as an abnormality of dental occlusion. Treatment of these incomplete Le Fort fractures may be conservative or may require completion of the fracture followed by fixation.

A given type of Le Fort fracture may not be bilateral but may occur in combination.[44] For example, there may be a Le Fort I of one side and a Le Fort II or III of the other side of the face. The Le Fort classification provides a succinct way of describing multiple fracture lines. In addition, use of the classification implies which bones are stable for attachment during surgical repair. Given this latter concept, it is critical not to misclassify the injury. For example, a bilateral Le Fort II plus a unilateral zygoma fracture is not the same as a Le Fort II on one side and a Le Fort III on the other side. The reason these classifications are not the same is the presence of the inferior orbital rim fracture when there is a bilateral Le Fort II plus a unilateral zygoma. The inferior orbital rim is not involved on one side in a Le Fort II and III combination. The inferior rim fracture cannot be overlooked in preoperative planning due to the risk of enophthalmos if orbital volume is not restored.

Another fracture involving part of the maxillary bone is the maxillary sagittal fracture.[45] This may be thought of as a unilateral Le Fort I with the fracture line passing in a sagittal plane through the hard palate. There may be an isolated fracture of part of the alveolar process of the maxillae. This is noted on physical examination as several teeth that are movable relative to the remainder of the teeth.

The midfacial smash fracture is a severely comminuted anterior facial injury.[41] The presence of severe comminution has implications for surgical repair and the portions of the facial buttresses, which must be stabilized. Three-dimensional images help to determine if adequate bone is present for placement of fixation devices. Assessment of the degree of comminution and bony discontinuities is necessary to decide if bone grafting is needed.[46]

Mandibular Fractures

Some mandibular fractures may be seen by plain radiographs, including a panorex view, and do not require CT. The sagittal condylar fracture, however, usually is not seen with plain radiographs and if mandibular symptoms persist CT is indicated for evaluation of the mandible. The tympanic plate of the temporal bone may fracture and is best seen with CT. Bleeding from the ear may occur with tympanic plate fractures. Otorrhagia can also be present with an intact skull base when there is a high condylar fracture. This type of condylar fracture is best imaged by coronal CT. The mandible is fractured in more than one place 50% to 60% of the time; about half the time a single fracture is seen. Fractures are described based on their location: parasymphyseal, body, angle, ramus, neck, condylar process, and coronoid process. The condylar fracture is the most frequently undiagnosed facial fracture.[20] A condylar fracture or dislocation is readily seen by coronal CT. If the alveolar ridge is involved, the fracture must be considered open. Mandibular fractures and their comminution, obliquity, and the degree of displacement resulting from muscular pull are readily seen by CT. Axial CT with 3-mm collimation in only the axial plane has been shown to be insufficient to detect posterior mandibular fractures. Helical CT should be performed in both axial and coronal planes when feasible, or 1-mm axial reformations should be used to reconstruct coronal images if the cervical spine has not been evaluated.

Frontal Sinus Fractures

The frontal sinus is a part of the calvaria but is frequently associated with facial bone fractures or may constitute an isolated fracture. The least serious injury is an isolated fracture of the anterior wall of the frontal sinus. These are usually depressed and may require elevation for cosmetic restoration. More serious is the fracture that also involves the posterior wall. Posterior wall fracture represents an open skull fracture and requires treatment with antibiotics. The frontal sinus fractures may be more extensive and involve the cribriform plate. Although difficult to demonstrate with CT, involvement of the cribriform plate becomes apparent clinically as cerebrospinal fluid rhinorrhea.

CERVICAL SPINE INJURY ASSOCIATED WITH FACIAL FRACTURES

When facial fractures are present, the incidence of concomitant cervical spine injury has been reported to be from 1% to 4%**.** In patients whose facial fractures are due to motor vehicle accidents (MVA), the incidence of cervical spine injury is between 5% and 6%. In a prospective study Beirne et a16 reported that 6 (1%) cervical spine injuries were found in 582 patients with facial fracture. These six injuries constituted 6% of the patients whose mechanism was MVA, and all the cervical spine injuries occurred in those patients who had been involved in an MVA. Only two of the cervical spine injuries were diagnosable on their standard three-view cervical spine plain radiograph series, four were diagnosable by CT, and two that were not initially recognized required flexion and extension views for diagnosis. In addition to MVA being the primary mechanism when cervical spine injury was seen to accompany facial injury, mandibular fractures were almost always present as one of the facial fractures. These findings suggest that patients with facial fractures sustained in an MVA should probably undergo cervical spine CT while in the scanner for their facial CT.

FACIAL INJURIES IN CHILDREN

Patterns of injury are different in children than in adults. Although nasal fractures are the most common injury, mandible fractures are the most frequent cause of hospitalization. In children the condyle accounts for more than half of mandible fractures in contrast to substantially less than half in adults. [32]Midfacial injuries are relatively rare in children compared with adults and tend to increase in frequency as the sinuses are pneumatized. When a midfacial fracture occurs due to major trauma the classic Le Fort patterns are not seen but an oblique orientation of fracture lines occurs across the injured parts of the face. Orbital roof fractures are relatively more common in children. Incomplete or greenstick fractures of facial bones are more common due to the more elastic bone in children.

BASIC CT IMAGING PARAMETERS

Computed tomography (CT) was first introduced as a clinical tool in 1971 when Drs. Godfrey Hounsfield and James Ambrose successfully diagnosed a brain tumor in a 41-year-old woman. In its most basic form, a rotating X-ray beam emits ionizing radiation of a defined thickness, which is used to irradiate the patient from numerous projections. Detectors located on the other side of the patient, opposite the source of the beam, register the amount of radiation that has penetrated through the patient. By calculating these values for numerous projections, a two-dimensional image of a specified thickness is generated. These images possess contrast resolution that is far superior to conventional radiography, demonstrating the ability to distinguish substances of only slightly different densities. Once such a 2-D image is acquired, the patient is advanced through the CT gantry for a predefined distance, and then the process is repeated. This is known as “step-and-shoot” technology.

Over the 20 years following its introduction, significant improvements in this technology were made. These advances were largely the result of improvements in X-ray beam emission and detector technology, matched by advances in computer technologies to facilitate the data processing of high level functions.

BASIC PRINCIPLES OF CT IMAGING

1.BEAM COLLIMATION (Slice Thickness)

Beam collimation relates to the actual thickness of the utilized X-ray beam. In conventional (nonspiral) CT, this defines the basic slice thickness. Thus, a 5mm thick beam leads to the generation of a 5mm thick section, a 10mm beam to a 10mm section, etc. Choosing a beam collimation (slice thickness) is often one of the first tasks in defining a CT scan sequence since this impacts the sensitivity of lesion detection of a study. When searching for small lesions, it would be a mistake to choose a thick slice section since the lesion could get lost in the slice due to volume averaging effects. With thinner sections, smaller lesions can be detected more easily, but also the quality of multiplanar and 3-D reformatted images will improve. Thinner collimation also results in less streak artifact off of high density objects (e.g. surgical hardware, clips, and bones) as compared to thicker sections. There are, however, several trade-offs in using thinner collimation. In conventional CT, using a thin collimation may lead to prohibitively long scan times due to the greater number of slices required to cover the anatomy.

There is also another trade-off to thinner slice collimation (slice thickness) and that is the effect it has on quantum noise. Quantum noise (also known as quantum mottle) is the noise in an image that is related to the number of photons utilized to generate that image. It is a statistical phenomenon. When many photons are utilized, the quantum noise is low. On the other hand, any image parameter manipulation that leads to a decrease in the numbers of photons will lead to an increase in quantum noise. This is where slice thickness comes in because this defines one of the three volumetric dimensions of a voxel. For an axial image, it delineates the margins of the voxel in the z-axis, or the longitudinal axis of the patient. By reducing the slice thickness in our example from 10mm to 2.5mm, we are decreasing the volume of the voxel by 75 percent. Now the number of photons per voxel is only 1/4 of what they would be in a 10mm slice, so the quantum noise rises by a factor of two. To the radiologist or clinician reviewing the image, this appears as reduced contrast resolution and takes it greatest toll on the ability to distinguish tissues with relatively subtle density differences.

There is one final point of much interest that should be made, and this relates to dose. Specifically, decreasing collimation in most situations does not lead to any significant change in dose administered to the patient, as long as the mAs and kV are not changed, even though the time needed to complete the study increases.

2. mAs and kV

The mAs directly relates to the number of photons emitted in an X-ray beam, and therefore inverselyto quantum noise. However, quantum noise is not solely the function of mAs. Any other imaging factor that affects the number of photons to reach a voxel will have an influence on quantum noise, including beam thickness (discussed above) and pixel size or matrix (see below).Heat units, which are the product of the mAs and kV, reflect the amount of energy loaded on theX-ray tube anode. The higher the mAs, the more limits in scan time and scan volume before the X-ray tube requires a cooling period. As previously mentioned, for imaging where soft tissue contrast is critical (e.g. distinguishing one soft tissue structure from another) a high mAs is beneficial; in evaluating high contrast regions (e.g. facial bones, spine), mAs is a much less important factor. Finally, of course, dosimetry is influenced by mAs, in a linear fashion where doubling the mAs doubles the patient dose. The kV is a reflection of the energy level of the X-ray beam. Higher energy beams offer greater penetration through the patient so that a greater number of photons reach the detectors. This will lead to smoother images due to a reduction in quantum noise, however, the contrast resolution between soft tissue structures may actually decrease due to the higher energy beam.

3. ROTATION

The rotation time is the time it takes for the X-ray beam to complete one 360° rotation. For conventional CT, this can vary up to four seconds. The benefit of a longer rotation time is the higher mAs it can deliver, leading to increased contrast resolution. However, longer rotation times may also allow greater patient

motion, thereby leading to net loss in image quality. Recently, significant improvements have been made in shortening rotation times for spiral CT sequences.

4. RESOLUTION

As a scan parameter, the term resolution relates to two issues: focal spot and secondary collimation. Marconi multislice scanners offer three resolution settings – standard, high, and ultrahigh. Changing from standard resolution to high resolution changes the focal spot from large to small. Changing from high to ultrahigh resolution maintains the small focal spot, but introduces a collimator in front of the detectors so that after the beam emerges from the patient, it is collimated before hitting the detectors. These collimators increase spatial resolution, but at the expense of lower dose efficiency since some of the photons are being discarded before reaching the detectors. As a result, quantum noise will go up (assuming mAs and kV are not changed). Resolution, as referred to in this context, is a true scan parameter. One must choose one of these resolution settings before the scanning begins. It cannot be altered after the data is collected since it relates to specific hardware employed during the scanning itself. Changing from one resolution setting to another has no impact on scan or reconstruction times, and similarly has no influence on image transfer times or archival space requirements.

5. RECONSTRUCTION FILTER (ALGORITHM)

During the course of a 360° rotation, a tremendous amount of data is generated. Once this scan data is accumulated, it is then passed through a mathematical filter algorithm as part of the image reconstruction process. Every CT unit offers multiple algorithms, each optimized for different body parts and tissue types. For example, a soft tissue algorithm may lead to smooth images, optimized to enhance soft tissue contrast, while a bone algorithm will sharpen bone margins at the expense of creating soft tissue windows limited by noise and poor soft tissue contrast. In general, each filter uses the same amount of time to process the data – i.e. no individual filter requires any more time than any other. Furthermore, images can be processed sequentially in multiple different filters as long as the raw scan data is saved, but this adds time to the overall study time and affects patient throughput.

In a more concrete, quantitative sense, one can define actual pixel size by understanding its relationship to the scan field of view, the reconstructed field of view, and the matrix.

$$\textbf{pixel size (mm)} = \frac{\textbf{field of view (mm)}}{\textbf{matrix}}$$

So if a scan is carried out with a field of view of 500mm, and the matrix used is 512 x 512, then:

$$\textbf{pixel size (mm)} = \frac{\textbf{500mm}}{\textbf{512}} = \textbf{0.98mm}$$

Each pixel is then approximately 1mm x 1mm. If a zoom factor is used, however, the formula must be modified since this effectively reduces the field of view, acting in the same way the zoom function on a camera reduces the visible area. So one may scan with a scanned field of view of 500mm, but if a zoom factor of 2 is then used, the reconstructed field of view becomes 250mm. Therefore, the full formula for pixel size is:

$$\textbf{pixel size (mm)} = \frac{\textbf{scanned FOV}}{\textbf{matrix x zoom}} = \frac{\textbf{reconstructed FOV}}{\textbf{matrix}}$$

Our goal is to match pixel size with spatial resolution afforded by the resolution setting (standard, high, ultrahigh) and reconstruction filter, as discussed above. This spatial resolution is expressed in terms of line pairs/cm. To convert this to millimeters, one can use the formula:

$$\textbf{Spatial resolution in mm} = \frac{\textbf{10}}{\textbf{2 x line pairs}}$$

7. ENHANCEMENT FACTORS AND FILTERS

Some manufacturers offer another family of filters known as enhancement factors. These filters can sharpen or smooth the images, and can be employed either at the outset of the study when the scan parameters are being defined, or after the images have already been reconstructed. If these enhancement factors are applied after the study has been reconstructed, it generally requires about 1-2 seconds per image for the enhancement to be applied. In some cases, even if a study has been retrieved from archival, the images can still be manipulated using these factors. Image transfer times and archival requirements are not affected by these factors.

LE FORT FRACTURES

Rene Le Fort [7] a French orthopedic surgeon first described his findings on the pattern of maxillary fractures based on cadaveric experiments performed around 1900. Milton Adams described in 1942 [8] and 1956 internal fixation with suspension and open reduction of the upper parts of the midface fractures by use of wires. In Le Fort fractures, Adams advocated open reduction and internal fixation of orbital rims in midface fractures by a combination of closed reduction of the lower midface, placement of intermaxillary fixation devices and placement of suspension wires leading to a point above the fracture on each side. These suspension wires were meant to compress or impact the maxillary segments, achieving a reduction. His principles were welcome because the external fixation devices were avoided in many patients. The limitation of the Adams technique related to the incomplete exposure and fixation of all fractured fragments and the use of compression with suspension wires as a means of facial fracture stabilization.

However, the midface would be shorter and wider after Adams fixation. Although Adams` technique served to simplify and improve the results of treatment and was satisfactory for simple, non-comminuted fractures, the technique failed to provide an opportunity to open or reduce the complete fracture patterns and restore all the comminuted segments of the fractures occurring between the maxillary alveolus and the orbit to their proper position. The technique also relied only on the bone fragments present, no matter what their condition. No early bone grafting was performed.

Advances in the last 20 years have revolutionized the treatment of Le Fort fractures, primarily with regard to the aesthetic (as opposed to functional) criteria. The advances are predicted on a better definition of the soft tissue or bone injury from CT scans and the use of extended open reduction techniques first involving exposures with fixation by wires, bone grafts, and internal fixation with plate and screw techniques. The use of bone grafts primarily to replace or to augment unusable bone structure was pioneered by Gruss [9] and rapidly spread throughout North America for the treatment of all facial injuries. These two techniques, rigid fixation of the facial skeleton and primary bone grafting allowed the preinjury bone architecture to be established before soft tissue contracture had occurred over a malpositioned bony skeleton. These techniques greatly improved the aesthetic results of treatment and have reduced the residual deformity by establishing a more accurate restoration of the preinjury craniofacial architecture.

Initially, wire interfragment fixation was used for bone alignment and reduction. These techniques did not produce rigid bone stabilization, as interfragment wires provide only a one dimensional force of apposition.[8] Three-dimensional stabilization of facial fracture fragments is achieved only my multiple wire points of fixation per fragment or preferably the use of a plate and screw technique that prevents the rotation of facial fracture fragments. Stability is provided by placement of two screws per bone fragment.

The use of Adams technique in comminuted fractures results in excessive midfacial compression and overlap, especially in crushed facial fractures. Midfacial height may be maintained only by a proper anatomic reconstruction of the vertical height of the maxillary buttresses. In the past attempts were made to establish restoration of midfacial height and projection with a head frame in addition to open reduction and interfragment wire technique in complicated fractures. The midface was set and stabilized to an exact relationship with the cranial base.

The bone reconstruction may now be more simply and securely performed by an anatomic surgical reconstruction of the horizontal and vertical structural pillars (fig 1.4,1.4A) of the midface.[8]

GOALS OF LE FORT FRACTURE TREAMENT

The goals of the treatment of Le Fort fractures are to reestablish midfacial height and projection.[10] to provide proper occlusion and to restore the integrity of the nose and orbit. The structural supports between the areas of the buttress and maxillary alveolus must also be restored to provide for the proper soft tissue contour. Fracture patterns exist as comminuted but standard discrete fracture segments corresponding in their boundaries to the lines of weakness of various levels of the Le fort fractures. The present classification of Le Fort fractures is actually a simplification of the fracture pattern described in his experiments and represents the application of the techniques of open reduction to Le Fort`s description. The Le Fort classification may be practically used to describe the most superior level of the fracture on each side because the fractures are usually bilaterally asymmetric. When Adams suspension wires were employed, the highest level of the fracture was the point beyond which the suspension had to be carried to achieve a stable reduction by compression. Now, the use of rigid fixation allows the stable point on each side to be the keystone to reduction of the lower midfacial fractures.

Ferraro and Berggren[11] were the first to document the reduced facial height that accompanies the usual Le Fort fracture treatment. Thus, in the treated Le Fort injury, the most common disturbance is reduced midfacial height and projection rather than the facial elongation and retrusion seen in the untreated Le Fort injury. It becomes important, therefore, to restore the facial height and projection by anatomic reconstruction of the buttress of the maxilla. Anteriorly the nasomaxillary and zygomaticomaxillary buttresses are reconstructed after the alignment, providing bone grafts and rigid fixation for stability. The fracture is usually worse on one side. The more intact side is usually the key to the facial height. Correction of the posterior facial height does not involve accurate reconstruction of the pterygoid buttresses but is achieved by intermaxillary fixation of the maxilla to an intact or anatomically reconstructed mandible. Therefore the posterior height of the mandible must be correct for a proper reconstruction of posterior maxillary midface height to be accomplished. Because the posterior maxilla is reduced by placing the maxilla in occlusion with the mandible, it becomes important to have the mandible reconstructed as a buttress for restoration of midfacial height and projection. Ramus and subcondylar fractures are stabilized by open reduction and rigid fixation.

LE FORT CLASSIFICATION

The heavier portions of the maxilla give strength to the bone; the thinner areas represent weakened sections through which fracture lines are likely to occur. The fracture lines travel adjacent to the thicker portions of the bone. Le Fort[7] completed experiments that determined areas of structural weakness of the maxilla, which he designated as “lines of weakness”. Between the lines of weakness were “areas of strength”. This classification led to the Le Fort classification of maxillary fractures, which identifies the patterns of midfacial fractures. The usual Le Fort fractures consists of combinations and permutations of these patterns so that straightforward pure bilateral Le Fort I, Le Fort II, or Le Fort III fractures are less common than combination patterns. The level of fractures on one side is different from that on the other, and the fracture is often more comminuted on the side of injury. Thus, it is common to see Le Fort III superior level fracture on one side with a Le Fort II superior level fracture on the other side with the shape of the segment carrying the dentition of a Le Fort I or II fracture.

TRANSVERSE (GUERIN) FRACTURES OR LE FORT I

Fractures that traverse the maxilla horizontally above the level of the apices of the maxillary teeth section the entire alveolar process of the maxilla, vault of the maxilla, and inferior ends of the pterygoid processes in a single block from the upper craniofacial skeleton. This type of injury is known as the transverse Le Fort I or Guerin fracture. This horizontal fracture extends transversely across the base of the maxillary sinuses and is almost bilateral. This horizontal fracture extends transversely across the base of the maxillary sinuses and is almost always bilateral. The fracture level varies from just beneath the zygoma to just above the floor of the maxillary sinus and the inferior margin of the piriform aperture. Lefort I level fractures may almost reach the inferior orbital rims and sometimes produce a pattern similar to that seen in a low Lefort II fracture or a high Lefort I osteotomy (fig 1.5).

PYRAMIDAL FRACTURES LEFORT II LEVEL FRACTURES

Blows to the central maxilla, especially those involving a frontal impact, frequently result in fractures with a pyramid – shaped central maxillary segment. This is a Lefort II central maxillary segment; the fracture begins above the level of the apices of the maxillary teeth laterally and posteriorly in the zygomaticomaxillary buttress and extends through the pterygoid plates in the same fashion as the Lefort I fracture. Fracture lines travel medially and superiorly to pass though the medial portion of the inferior orbital rim and extend across the nose high or low to separate superior cranial from midfacial structures (Fig 1.6). This fracture, because of its general shape and configuration, has become known as the pyramidal fracture of the maxilla or the Lefort II fracture. The degree of variability of the fracture in terms of the level at which it crosses the nose is extreme. It may extend through the nasal cartilages on one side (low) or through the distal nasal bone on the other side or may separate the nasal bones from the glabella at the junction of the nasal bones and frontal bone (high). With high-energy central midface impacts, the frontal sinus may be fractured and even comminuted because it is adjacent to the upper part of a high Lefort II segment. Damage to the ethmoidal areas is routine in pyramidal fractures; these are weak areas through which fracture lines traverse the medial orbit. The lacrimal system may be involved if fracture lines traverse the lacrimal fossa. With increasing force of fracture, fractures include the combination of Lefort I and II fractures with or without a split palate.

CRANIOFACIAL DISJUNCTION OR LEFORT III FRACTURES

Craniofacial disjunction may occur when the fracture extends through the zygomaticofrontal suture and the nasal frontal suture and across the floor of the orbits to effectively separate all midfacial structures from the cranium. In these fractures, the maxilla is usually separated from the zygoma, but occasionally (5% of Lefort III fractures) the entire midface may be a large single fragment, which is often only slightly displaced and immobile. These fractures are usually minimally displaced and present only with “black eyes” and with subtle occlusal problems. The Lefort III segment may or may not be separated through the nasal structures. In these fractures, the entire midfacial skeleton is incompletely detached from the base of the skull and suspended by the soft tissues and greenstick fracture (Fig 1.7)

CLINICALLY RELEVANT INFORMATION

Facial Buttresses

The key to understanding Le Fort's work is the strength (thickness) of the bony supports of the face. The alveolar process of the maxilla and the malar eminence of the zygoma are the thickest bony areas and they are relatively resistant to fracture. The nasofrontal process of the maxilla also tends to be spared.[37] The bony attachments of the alveolar process of maxilla and malar eminence are less strong but constitute the facial buttresses that hold the thicker bony structures in place.

These are more likely to fracture than the thicker bone. These buttresses include the pterygomaxillary buttress, the zygomatic buttress, the nasofrontal buttress, and the orbital buttress. The pterygomaxillary buttress is formed by the pterygoid plates and posterior wall of maxillary sinus. The zygomatic buttress is formed by the frontal process of zygoma and zygomatic process of the frontal bone, the zygomatic arch, and the region connecting the malar eminence to the alveolar process of the maxilla. The nasofrontal buttress is formed by the nasal process of the maxilla and medial orbital rim. The orbital buttress is formed by the entire orbital rim. The mandible itself constitutes the mandibular buttress. After injury, return of the face to functional and cosmetic integrity involves restoration of facial height, width, and depth. This involves identification of portions of the buttresses that remain fixed to the skull. Reattachment of the fractured portions of the buttresses to their stable components should restore facial alignment.

Facial Struts

In addition to the facial buttresses, an additional concept to plan repair of facial fracture involves identifying the portions of the major struts of the face that remain attached to the skull or the intact part of the face. These struts include the thicker and the thinnest bones of the face, whereas the buttresses include only the thicker supporting bony areas. Gentry et al [30] described these struts as being oriented in the horizontal, sagittal, and coronal planes. The struts are constituted by all the facial bones excluding the mandible. There are three horizontal struts: (1) the superior, (2) middle, and (3) inferior. The superior horizontal strut is composed of the orbital roofs, planum sphenoidale, and the cribriform plate. The middle horizontal strut is composed of the orbital floors and zygomatic arches. The inferior horizontal strut is made up by the hard palate and alveolar process of the maxilla. There are two coronal struts: (1) the anterior and (2) posterior. The anterior coronal strut is composed of the anterior walls of the maxillary sinuses There are five sagittal struts: the midline, two parasagittal, and two lateral. The midline sagittal strut is composed of the bony and cartilaginous nasal septum including the vomer and perpendicular plate of the ethmoid. The parasagittal struts are each composed of the medial wall of the orbit, the medial wall of the maxillary sinus, and the ipsilateral pterygoid plate. The lateral sagittal struts are each formed by the lateral wall of the orbit, the lateral wall of the maxillary sinus, and the lateral alveolar process of the maxilla. The concept of these struts in three planes requires imaging of the face in both axial and coronal orientations if possible in order to determine the existence of fractures, their comminution, and their displacement.

CLASSIFICATION OF LEFORT FRACTURES

The highest level and components of the fracture on each side

Lefort I : Maxillary alveolus

Split palate

Alveolar tuberosity fracture

Lefort II : Pyramidal fracture

Lefort III : Craniofacial disjunction

Lefort IV : Frontal bone

Pattern of fragment that includes the maxillary dentition (“occlusal fragment”)

Associated fractures

Mandible

Nasoethmoido-orbital

Frontal sinus

CT DIAGNOSIS OF LEFORT FRACTURES

The pterygoid process are broken in all types of Le Fort fractures.[12] The Le Fort I fracture is the only one that involves the anterolateral margin of the nasal fossa just above the maxillary alveolar process. This fracture of the anterolateral margin of the nasal fossa is easily seen on coronal or 3D CT images of the face. If the pterygoid processes are broken and this portion of the maxilla is broken, a Le Fort I fracture most likely is present. If the anterolateral margin of the nasal fossa is intact, a Le Fort I fracture is excluded. The Le Fort II fracture is the only one that involves the inferior orbital rim. The inferior orbital rim is also easily seen on coronal or 3D CT images of the face. If the pterygoid processes are broken and the inferior orbital rim is broken, probably a Le Fort II fracture is present. If the inferior orbital rim is intact, a Le Fort II fracture is excluded. The Le Fort III fracture is the only one that involves the zygomatic arch. The zygomatic arch is easily seen on axial or 3D CT images of the face. If the pterygoid processes are broken and the zygomatic arch is broken, probably a Le Fort III fracture is present. If the zygomatic arch is intact, a Le Fort III fracture is excluded (fig 1.5)

Three Steps in Diagnosing a Le Fort Fracture

First, always look at the pterygoid processes, especially on coronal images. A fracture of the pterygoid processes almost always indicates that fractures in at least one of the Le Fort planes are present. Second, to classify the type of Le Fort fracture, look at the three bony structures that are unique to a given type of Le Fort fracture: the anterolateral margin of the nasal fossa, the inferior orbital rim, and the zygomatic arch. If one of these structures is intact, the corresponding type of Le Fort fracture is excluded. If one of these structures is broken, the corresponding type of Le Fort fracture is most likely present. Third, if one of the Le Fort fractures is suspected because of a break in its unique component, the fracture should be confirmed by identifying the other fractures that would be expected in the plane of that type of Le Fort fracture.

ANALYZING FACIAL CT

The ease of interpretation of facial injuries is facilitated by considering the previously described regions of the face and their supporting attachments to the skull and rest of the face as well as the types of fractures frequently seen. Visual patterns of search during interpretation differ among different radiologists. Starting at the top and working down using the axial images and then the coronal images is useful in detection of the first abnormality. A common mistake, especially by

those new to facial CT interpretation, is to continue the top-down approach while making an unorganized list of each tiny fracture that can be seen. Once the first fracture is seen, it is more efficient to think of which regions of the face could be involved and to go immediately to their major supporting structures. For example, starting with the axial images if the first fracture recognized is the zygomatic arch, the patient has an injury involving the zygomatic region. The zygomatic arch may be injured alone or as a component of a Le Fort fracture. Thus, after seeing the arch fracture it is helpful to go to the images that depict the frontal process of zygoma and the inferior orbital rim. If these are fractured, at least there is a zygoma complex fracture. If these are intact, there may be only an isolated arch fracture. If the zygomatic arch is fractured as a component of a Le

Fort injury, it is helpful to look for the pterygoid plates on the coronal images. All the Le Fort fractures break the pterygoid plates. Intact pterygoid plates exclude all the Le Fort fractures including the Le Fort III, which is the only Le Fort fracture that involves the arch. The previous example illustrates one pattern for find the first fracture consider which region of the face is involved by this fracture look at the major pieces of bone that support this region if the major supporting bone also involves an adjacent region, then evaluate the major bony structures supporting that adjacent region when a type or classification of fracture becomes apparent, investigate whether the thinner pieces of bone that should be fractured are in fact involved conclude with similar analysis of the remaining regions of the face It is essential not to terminate the search with the bone windows. Orbital and other soft tissue injury is much more easily seen on the soft tissue windows. It is comforting to note the absence of fluid in the sinuses. A clear sinus correlates with absence of midfacial fractures that involve a sinus wall.[29] The presence of fluid can be seen due to soft tissue injury with or without fracture or incidentally with pre-existing sinusitis.

Avoiding Pitfalls

One pitfall is to rely on the clinical history that resulted in a diagnosis based on physical examination. The physical findings of a Le Fort fracture may not always be present. Another pitfall is to terminate a search of the images after identifying one Le Fort fracture. Fractures may occur in more than one Le Fort fracture plane on the same side. For example, there may simultaneously be Le Fort II and III fractures on the same side. To avoid this pitfall, look at all three unique components of the Le Fort fractures even after one component is seen to be fractured. A third pitfall is to expect that Le Fort fractures are bilaterally symmetric. Fractures can occur in different Le Fort planes on each side. For example, a Le Fort I fracture may occur on one side and another type of Le Fort fracture on the contralateral side. To avoid this pitfall, look at the pterygoid processes and each of the three unique components first on one side and then on the other side. A fourth pitfall is the occurrence of a Le Fort fracture simultaneously with other facial fractures. Having postulated that a Le Fort fracture is present because of a fracture of the pterygoid processes and a unique Le Fort component, it is necessary to confirm the type of Le Fort fracture that you think is present and look for fractures that do not fit the plane of the Le Fort fracture you have diagnosed. Confirming the type of Le Fort fracture involves ensuring that fractures are seen throughout the plane of the expected Le Fort fracture type.

Diagnostic Difficulties.

1. 2D CT gives a better idea about soft tissue injuries as compared to 3D CT especially in blow out fracture of the orbit and this can alter the management of reconstruction of the floor by either using alloplastic material or costochondral grafts.

2. Undisplaced fractures are better picked up by 2D CT as compared to by 3D CT.

3. The crucial importance of 3D CT over 2D CT is seen in comminuted and displaced fractures.

4. “Pseudoforamina” ie artifactual defects in the thin bones commonly involving the inferior and medial orbital walls may create improper readings of 3D CT.

MATERIAL AND METHODS

This is a prospective study of 34 cases for a duration of 2 years from August 2006 to August 2008. The study was conducted in the Department of Plastic and Reconstructive Surgery, CMC Vellore.

Patients coming to the Accident and Emergency Department with alleged history of road traffic accidents were clinically assessed .If a clinical diagnosis of facial bone fracture was made then the patients were initially subjected standard radiographic procedures including conventional X-Rays and then to 2D CT and if a diagnosis of LeFort fracture was made then a 3D CT was performed.

Images were manipulated to provide optimal 3D demonstration of the fractures, using proprietary software tools that permitted manipulating the level of transparency, altering the angle of lighting on surfaces, changing the color tone of the surfaces and selectively cropping the image to provide multiple viewing angles.

Each of the 2D CT scans were read by the co-investigator who was a board certified radiologist and the various fracture sites determined. The 3D CT scans were then evaluated by the principal investigator for fractures and then both scans will be compared to see if any additional information was obtained.

The 2D and 3D scans were then randomized and reread by the principal investigator and radiologist and the data was statistically analyzed to see if 3D reconstruction played an important role in interpreting fractures and whether additional information was obtained from the 3D CT and if this changed the surgical planning and thus had a bearing on the treatment modality.

The various fracture sites that were examined included the frontal bone, nasal bone, zygoma, zygomaticomaxillary buttress, nasomaxillary buttress, infraorbital margins on both sides and the mandible.

A total of 374 sites were examined for fractures on both the 2D and 3D separately. Associated injuries were also recorded. However soft tissue lacerations were not recorded as associated injuries.

Inclusion Criteria

a) All patients within the ages of 15 to 60 years
b) No associated co-morbid conditions
c) Patients with associated bony and soft tissue injuries
d) Patients with mild to moderate head injury

Exclusion Criteria

a) Children and patients more than 60 years of life
b) Patients with co-morbid conditions
c) Patients with severe head injury

CT SCAN INFORMATION:

The CT scan used was Philips Medical System, Nederlands BV, Brilliance CT.

It used a Collimation of 6 X 0.75 with a pixel of 0.9

The Reconstruction Matrix Rotation Time was 0.75 sec

The Matrix was 512 X 512

Software used was version- v23.0.1340

Slice Thickness- 2mm

ASSESSMENT OF FACIAL FRACTURES

The Le Fort I fracture is the only one that involves the anterolateral margin of the nasal fossa just above the maxillary alveolar process. This fracture of the anterolateral margin of the nasal fossa is easily seen on coronal or 3D CT images of the face. If the pterygoid processes are broken and this portion of the maxilla is broken, a Le Fort I fracture most likely is present. If the anterolateral margin of the nasal fossa is intact, a Le Fort I fracture is excluded.

The Le Fort II fracture is the only one that involves the inferior orbital rim. The inferior orbital rim is also easily seen on coronal or 3D CT images of the face. If the pterygoid processes are broken and the inferior orbital rim is broken, probably a Le Fort II fracture is present. If the inferior orbital rim is intact, a Le Fort II fracture is excluded.

The Le Fort III fracture is the only one that involves the zygomatic arch. The zygomatic arch is easily seen on axial or 3D CT images of the face. If the pterygoid processes are broken and the zygomatic arch is broken, probably a Le Fort III fracture is present. If the zygomatic arch is intact, a Le Fort III fracture is excluded.

STEPS IN DIGNOSING A LE FORT FRACTURE

First, always look at the pterygoid processes, especially on coronal images. A fracture of thepterygoid processes almost always indicates that fractures in at least one of the Le Fort planes are present.

Second, to classify the type of Le Fort fracture, look at the three bony structures that are unique to a given type of Le Fort fracture: the anterolateral margin of the nasal fossa, the inferior orbital rim, and the zygomatic arch. If one of these structures is intact, the corresponding type of Le Fort fracture is excluded. If one of these structures is broken, the corresponding type of Le Fort fracture is most likely present.

Third, if one of the Le Fort fractures is suspected because of a break in its unique component, the fracture should be confirmed by identifying the other fractures that would be expected in the plane of that type of Le Fort fracture.

DATA ANALYSIS

The agreement statistic used for data analysis was the Kappa statistics and Chi square test to assess the 2D and 3D results for comparison.

To test the association between mode of injury and other associated injuries the Chi square test was used.

Sensitivity and Specificity of 3D comparing 2D as the standard was done using the SPSS 11.0 for windows software.

OBSERVATION AND RESULTS

Crosstabs of Frontal Bone Fractures

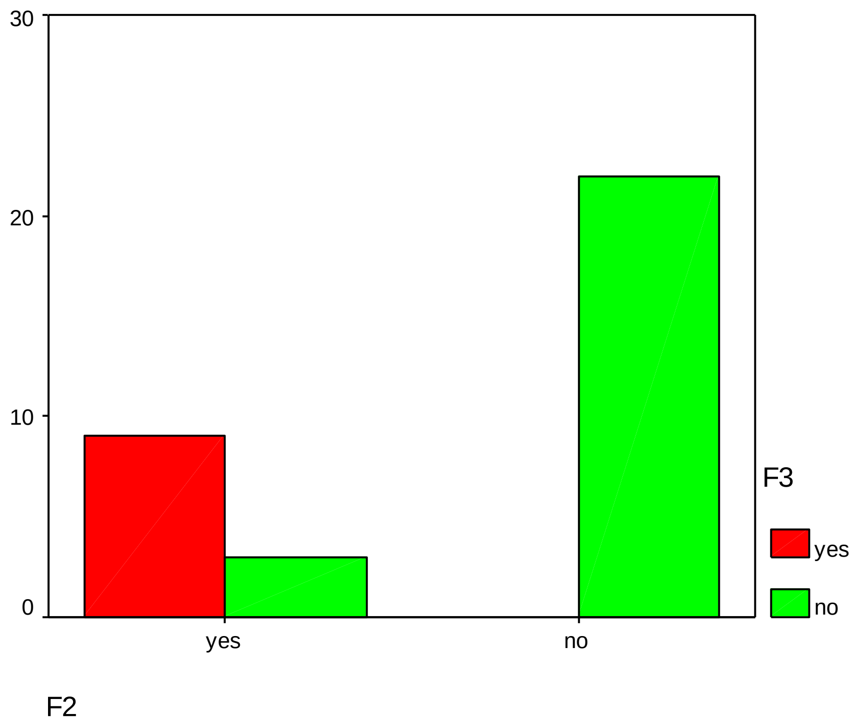

Figure 1

Total number of positive finding on 2D of Frontal bone fractures is 12, of which, 9 (75%) are classified as positive by 3D of Frontal bone and 3 (25%) are classified negative by the same. Of the negatives as per Frontal bone fractures on 2D, all of them are classified as negatives by 3d of frontal bone also. The measurement of agreement kappa = 0.795 ($p < 0.001$).

Crosstabs of Right Fronto-Zygomatic Buttress Fractures

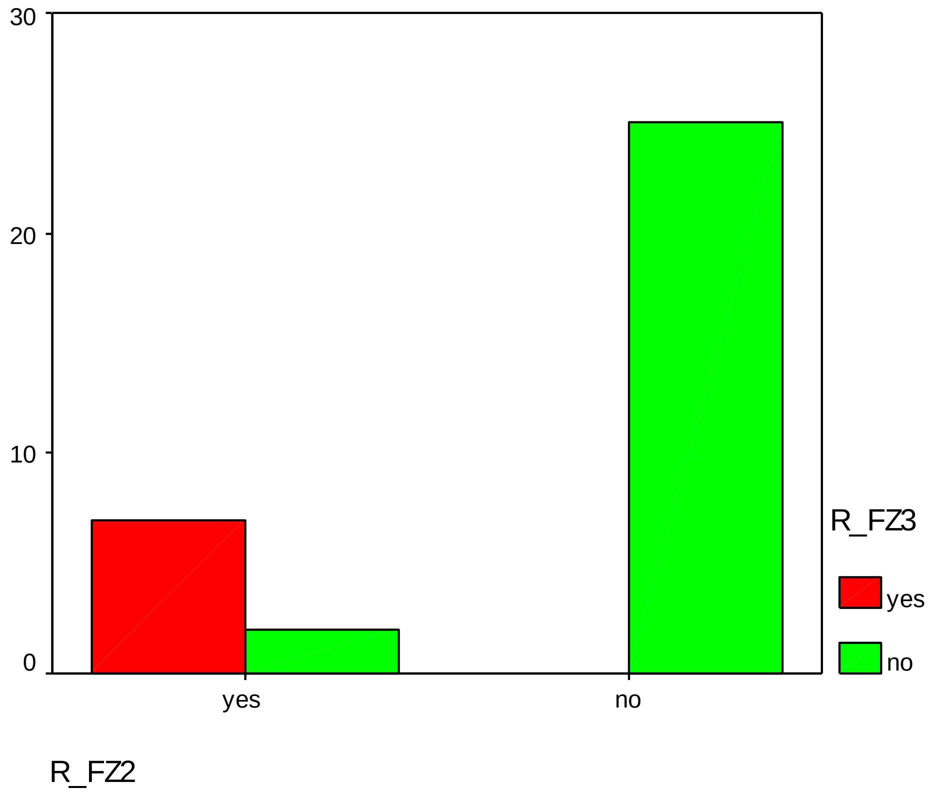

Figure 2

Total number of positive finding on 2D of Right Frontozygomatic buttress is 9, of which, 7 (78%) are classified as positive by 3D of Right Frontozygomatic buttress and 2 (22%) are classified negative by the same. Of the negatives as per 2D of Right Frontozygomatic buttress, all of them are classified as negatives by 3D of Right Frontozygomatic also. The measurement of agreement kappa = 0.837 ($p < 0.001$).

Crosstabs of Left Fronto-Zygomatic Buttress Fractures

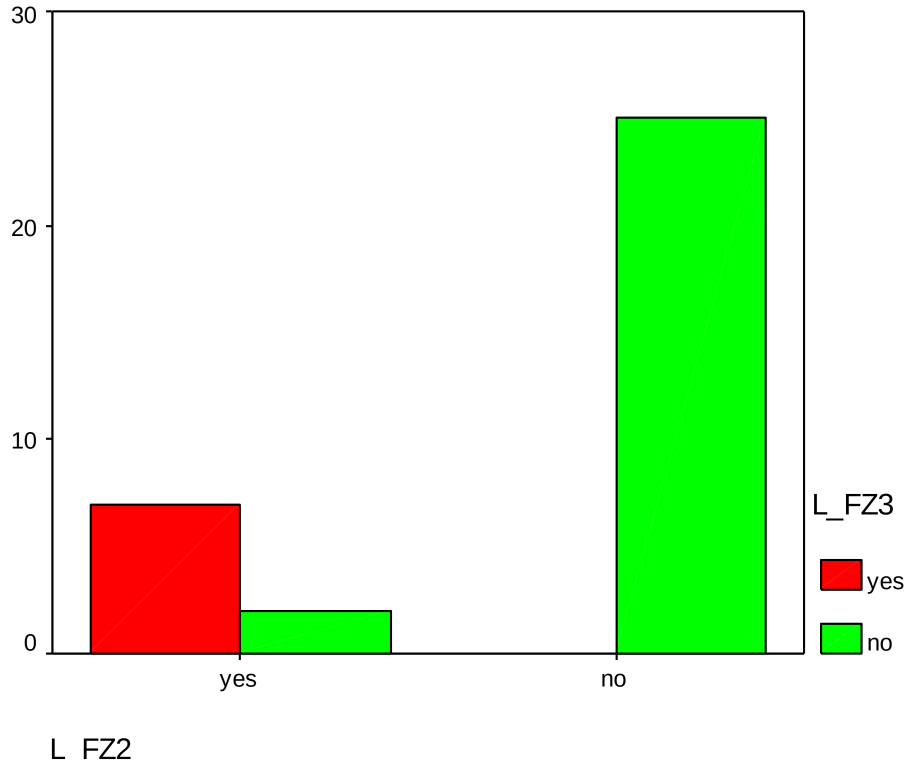

Figure 3

Total number of positive finding on 2D of Left Frontozygomatic buttress is 9, of which, 7 (78%) are classified as positive by 3D of Left Frontozygomatic buttress and 2 (22%) are classified negative by the same. Of the negatives as per 2D of Left Frontozygomatic buttress, all of them are classified as negatives by 3D of Left Frontozygomatic buttress also. The measurement of agreement kappa = 0.837 ($p < 0.001$).

Crosstabs of Nasal Bone Fractures

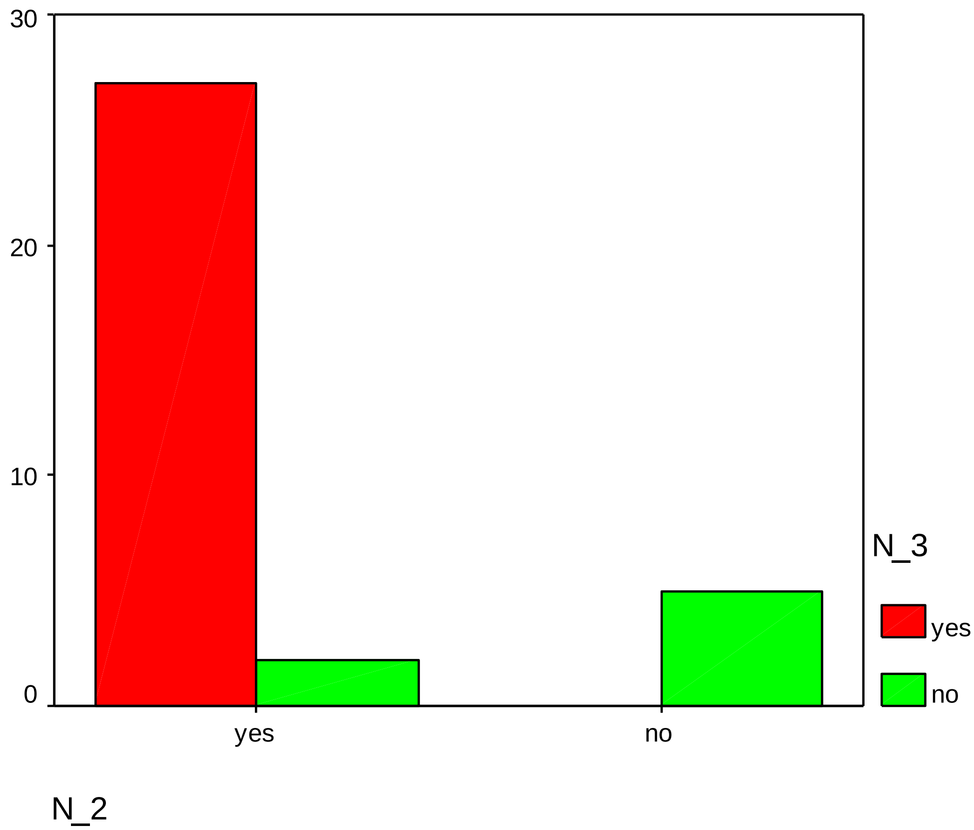

Figure 4

Total number of positive finding on 2D of Nasal bone fractures is 29, of which, 27 (93%) are classified as positive by 3D of Nasal bone fractures and 2 (7%) are classified negative by the same. Of the negatives as per 2D of Nasal bone fractures, all of them are classified as negatives by 3D of Nasal bone fractures also. The measurement of agreement kappa = 0.799 ($p < 0.001$).

Crosstabs of Right Zygomatico-Maxillary Buttress Fractures

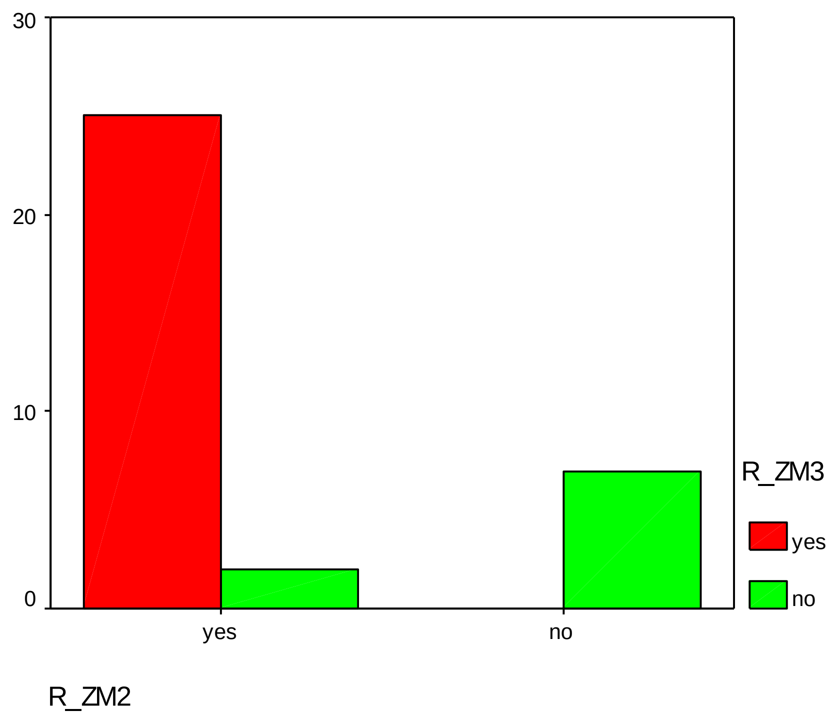

Figure 5

Total number of positive finding on 2D of Right Zygomaticomaxillary buttress is 27, of which, 25 (93%) are classified as positive by 3D of Right Zygomaticomaxillary buttress and 2 (7%) are classified negative by the same. Of the negatives as per 2D of Right Zygomaticomaxillary buttress , all of them are classified as negatives by 3D of Right Zygomaticomaxillary buttress also. The measurement of agreement kappa = 0.837 ($p < 0.001$).

Crosstabs of Left Zygomatico-Maxillary Buttress Fractures

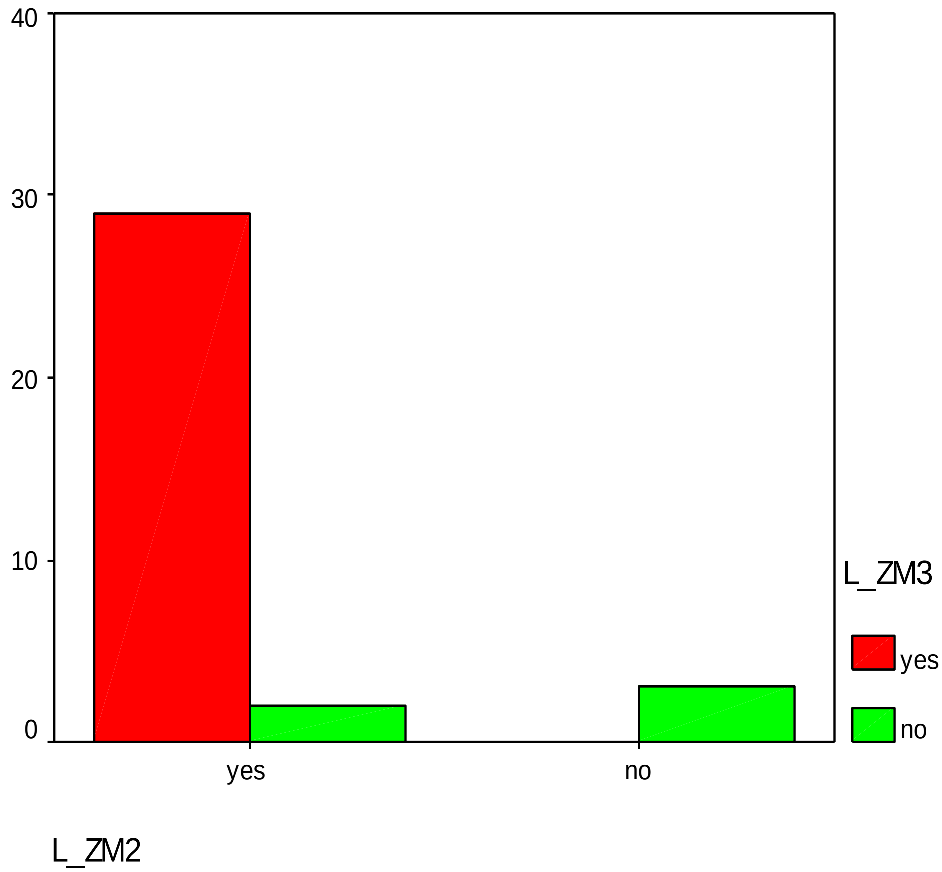

Figure 6

Total number of positive finding on 2D of Left Zygomaticomaxillary buttress is 31, of which, 29 (93.5%) are classified as positive by 3D of Left Zygomaticomaxillary buttress and 2 (7.5%) are classified negative by the same. Of the negatives as per 2D of Left Zygomaticomaxillary buttress, all of them are classified as negatives by 3D of Left Zygomaticomaxillary buttress also. The measurement of agreement kappa = 0.719 ($p < 0.001$).

Crosstabs of Right Naso-Maxillary Buttress Fractures

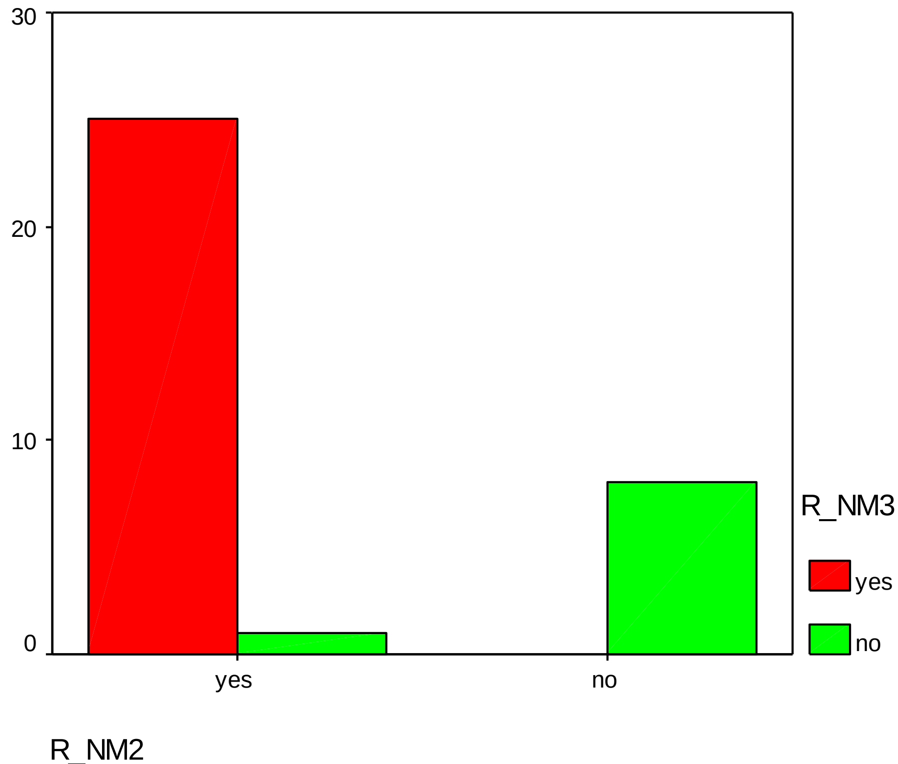

Figure 7

Total number of positive finding on 2D of Right Nasomaxillary buttress is 26, of which, 25 (96%) are classified as positive by 3D of Right Nasomaxillary buttress and 1 (4%) are classified negative by the same. Of the negatives as per 2D of Right Nasomaxillary buttress , all of them are classified as negatives by 3D of Right Nasomaxillary buttress also. The measurement of agreement kappa = 0.922 ($p < 0.001$).

Crosstabs of Left Naso-Maxillary Buttress Fractures

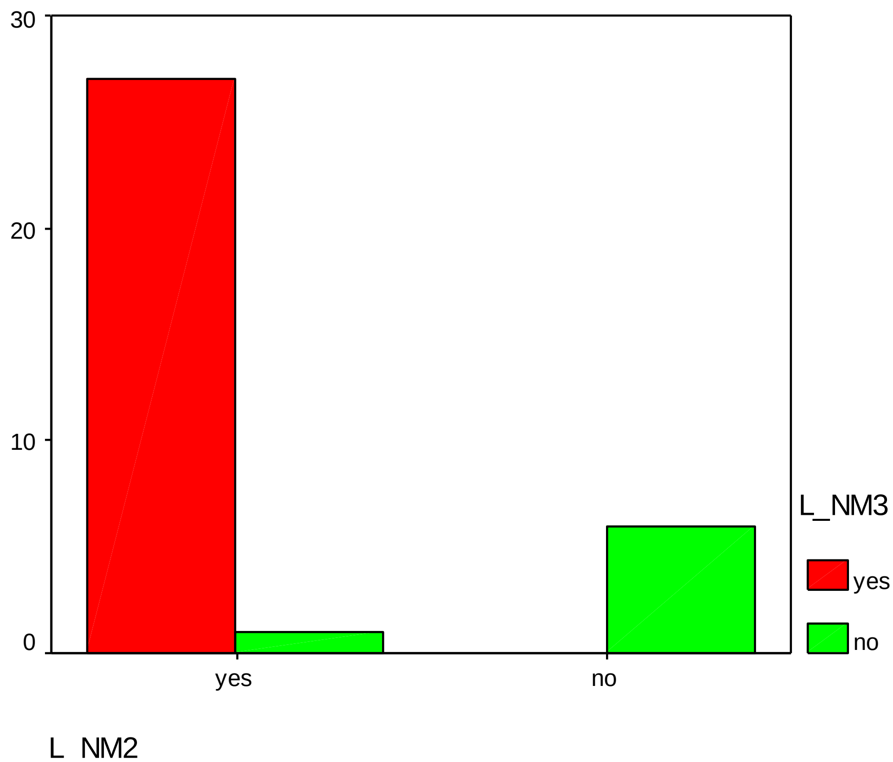

Figure 8

Total number of positive finding on 2D of Left Nasomaxillary buttress is 28, of which, 27 (96%) are classified as positive by 3D of Left Nasomaxillary buttress and 1 (4%) are classified negative by the same. Of the negatives as per 2D of Left Nasomaxillary buttress , all of them are classified as negatives by 3D of Left Nasomaxillary buttress also. The measurement of agreement kappa = 0.905 (p < 0.001).

Crosstabs of Right Infraorbital Rim Fractures

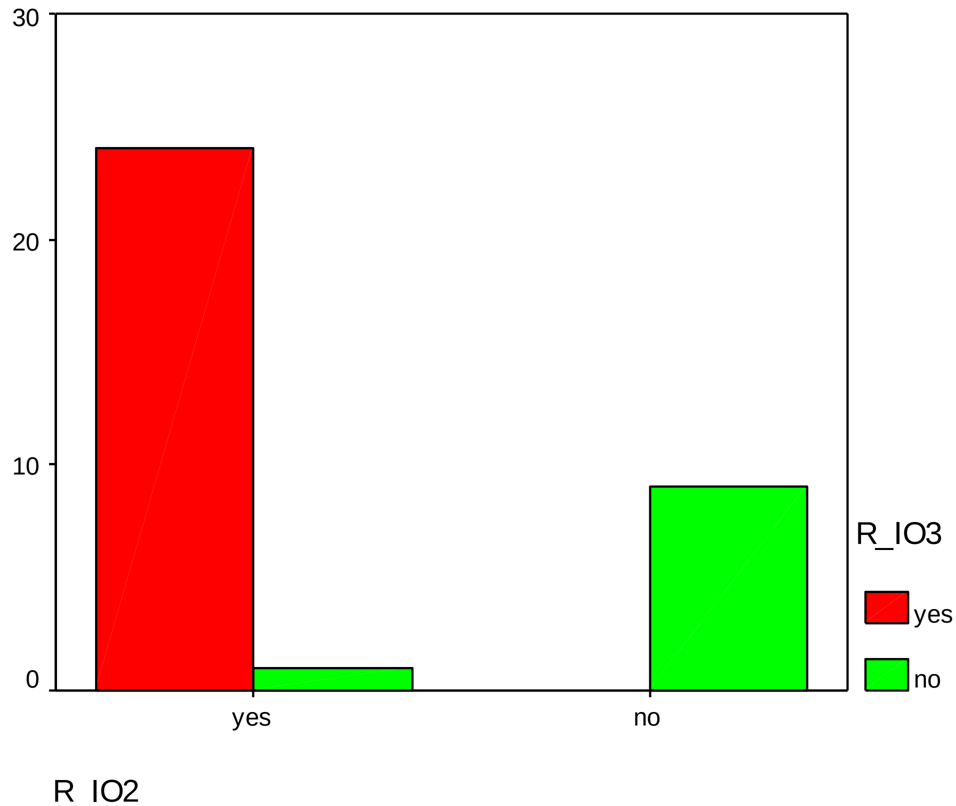

Figure 9

Total number of positive finding on 2D of Right Infraorbital rim is 25, of which, 24 (96%) are classified as positive by 3D of Right Infraorbital fractures and 1 (4%) are classified negative by the same. Of the negatives as per 2D of Right Infraorbital rim , all of them are classified as negatives by 3D of Right Infraorbital fractures also. The measurement of agreement kappa = 0.927 ($p < 0.001$).

Crosstabs of Left Infraorbital Rim Fractures

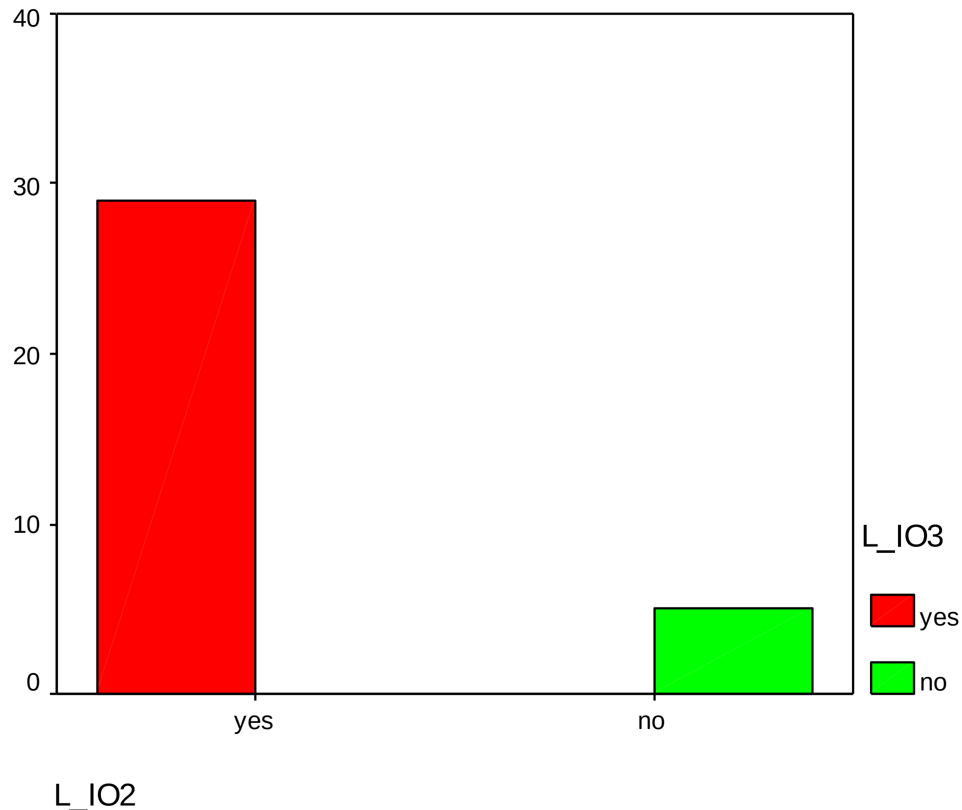

Figure 10

Total number of positive finding on 2D of Left Infraorbital rim is 29, of which, all are classified as positive by 3D of Left Infraorbital rim. Of the negatives as per 2D of Left Infraorbital rim , all of them are classified as negatives by 3D of Left Infraorbital rim also. The measurement of agreement kappa = 1.00 ($p < 0.001$).

Crosstabs of Mandibular Fractures

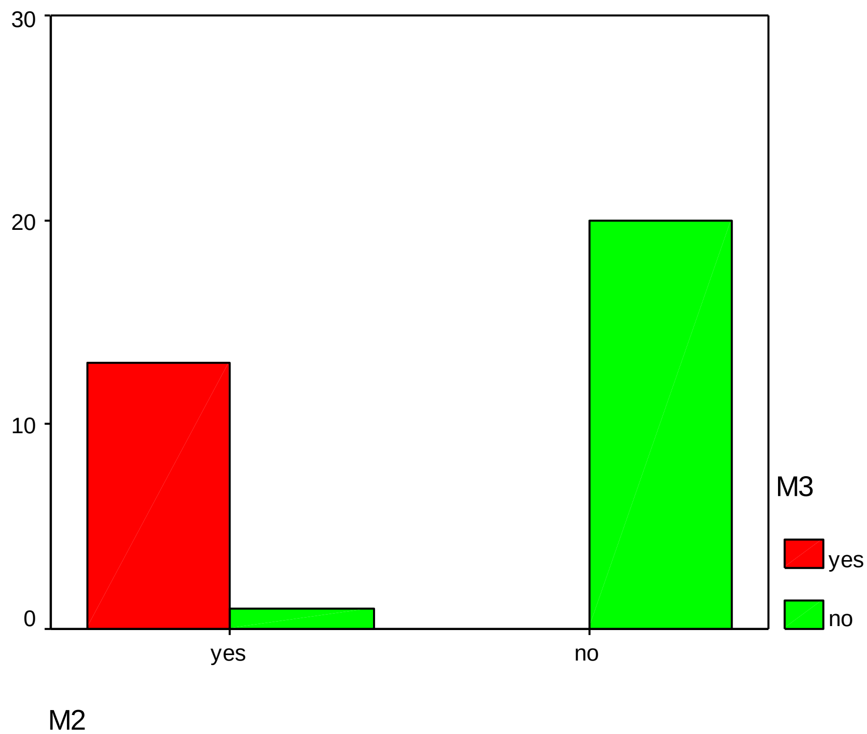

Figure 11

Total number of positive finding on 2D of Mandible fractures is 14, of which, 13 (93%) are classified as positive by 3D of Mandible fractures and 1 (7%) are classified negative by the same. Of the negatives as per 2D of Mandible fractures, all of them are classified as negatives by 3D of Mandible fractures also. The measurement of agreement kappa = 0.939 ($p < 0.001$).

Data Analyses:

All statistical analyses were performed using SPSS 11.0 for windows. Microsoft Excel was used for graphs. Crosstabulations and Kappa statistics are used to present the agreement between the 2D and 3D CT reconstruction for Lefort fractures. A p-value <0.05 is considered statistically significant.

Diagnosis of Various fracture sites

Figure 12 shows fractures of the right side picked up by 2D CT. Here it is seen that 9% had isolated Lefort I, 6% had Lefort II and 3% had Lefort III. 17% had Lefort I and II, 3% had Lefort I and III , 3% had Lefort II and III and 15% had Lefort I,II and III. 44% of patients did not have any fractures on the right side.

Figure 13 shows fractures of the right side picked up by 3D CT. Here it is seen that 12% had isolated Lefort I, 6% had Lefort II and 3% had Lefort III. 20% had Lefort I and II, 3% had Lefort II and III and 15% had Lefort I,II and III. 44% of patients did not have any fractures on the right side.

Figure 14 shows fractures of the left side picked up by 2D CT. Here it is seen that 1% isolated Lefort I, 5% had Lefort II, 2% had Lefort III, 7% had Lefort I and II, 5% had Lefort I,II and III. 14% had no fractures.

Figure 15 shows fractures of the left side picked up by 3D CT. Here it is seen that 1% isolated Lefort I, 6% had Lefort II, 2% had Lefort III, 7% had Lefort I and II, 4% had Lefort I,II and III. 14% had no fractures.

Figure 16 shows bilateral fractures picked up by 2D CT. Here it is seen that 1% isolated Lefort I, 2% had Lefort II, 2% had Lefort III, 6% had Lefort I and II, 2% had Lefort I,II and III. 21% had no fractures.

Figure 17 shows bilateral fractures picked up by 3D CT. Here it is seen that 1% isolated Lefort I, 2% had Lefort II, 2% had Lefort III, 6% had Lefort I and II, 2% had Lefort I,II and III. 21% had no fractures.

DISCUSSION

Although 2D axial and coronal CT is more accurate and more sensitive than 3D reformatting, numerous studies have explores the utility of 3D imaging. Three-dimensional images are created from the original 2D slices; therefore, there is no new information in the images and artifacts may be produced in the reformation process. Nonetheless, reconstructed 3D images may assist in the visualization of large comminuted, displaced and complex fractures involving multiple planes, particularly in regard to the midface.[12] To accurately assess symmetry and fracture lines, reconstructed images must be angulated carefully to exclude any false positives.[13] 3D images provide only information regarding bony architecture; fat and muscle entrapment, encephaloceles, haematomas, and associated injuries must be assessed radiographically through 2D CT manipulation of soft-tissue windows.

Fox found that 3D reconstructed CT scans were interpreted more rapidly and more accurately by clinicians and that 3D CT was more accurate at assessing zygomatic fractures but was inferior to axial images for evaluation orbital fractures.[14] Other studies have also described 3D CT as being most useful for imaging comminuted fractures of the middle third of the face and the zygomatico-maxillary complex.[15,16] Hessel demonstrated that these 3D CT scans altered or cancelled surgical procedures, particularly in nasoorbital-ethmoid fractures.[17] These observations indicate that 3D scans enable clinicians to better assess the localization of bone fragments and their direction of displacement. 3D imaging is not indicated however for small fractures of the orbital floor or isolated fractures of the maxillary wall, in which the fracture is limited to one plane.

Here, examining 3D scans alone can give false-negative results.[13, 15] With this in mind it is useful to think of 3D imaging as a complemantary study that can add important information to multiplanar imaging.

Reuben et al. reported that individuals at different levels of experience showed differential appreciation for traumatic injuries illustrated by radiograph, 2D CT and 3D CT reconstruction.[18] Nonradiologist viewers correctly diagnosed the fractures in 75.7% of 3D cases, 71.5% of radiographs and 64.7% of conventional CT.[18] Viewers shoed a preference for 3D CT over conventional CT over radiographs in a survey conducted as a part of this study and a similar survey performed by Alder also demonstrated that surgeons preferred 3D reconstruction to 2D versions for treatment planning. However experienced radiologists continue to prefer and interpret 2D CT better than 3D. These findings underscore the importance of 3D CT as a valuable tool at training institutions but also substantiate the need for evaluation of 2D CT by an experienced radiologist and for subsequent availability of 3D reconstruction for review by surgeons.

Patients incur no additional risk secondary to 3D CT; the scans are formatted using the 2D images and require no additional scanning or radiation exposure. Although there is increased interpretation time for the radiologist recent trends in 3D prototyping have drastically imporved the processing time and cost and thereby the accessibility, of these images. It is now possible to routinely access images with 0.5-mm slices for reconstruction that produce high-resolution images with little artifact. Radiologists can now use computer graphic systems to manipulate volumetric data and present their quantitative information in a manner more useful to surgeons for preoperative planning.[15]

In this study there are various results for each fracture site showing that 2D CT is more accurate than 3D CT.

In the case of all the frontal bone fractures the total number of positive finding on 2D of Frontal bone fractures is 12, of which, 9 (75%) are classified as positive by 3D of Frontal bone and 3 (25%) are classified negative by the same. Of the negatives as per Frontal bone fractures on 2D, all of them are classified as negatives by 3d of frontal bone also. The measurement of agreement kappa = 0.795 ($p < 0.001$).

For right frontozygomatic fractures the total number of positive finding on 2D of Right Frontozygomatic buttress is 9, of which, 7 (78%) are classified as positive by 3D of Right Frontozygomatic buttress and 2 (22%) are classified negative by the same. Of the negatives as per 2D of Right Frontozygomatic buttress, all of them are classified as negatives by 3D of Right Frontozygomatic also. The measurement of agreement kappa = 0.837 ($p < 0.001$).

For left frontozygomatic fractures Total number of positive finding on 2D of Left Frontozygomatic buttress is 9, of which, 7 (78%) are classified as positive by 3D of Left Frontozygomatic buttress and 2 (22%) are classified negative by the same. Of the negatives as per 2D of Left Frontozygomatic buttress, all of them are classified as negatives by 3D of Left Frontozygomatic buttress also. The measurement of agreement kappa = 0.837 ($p < 0.001$).

For nasal bone fractures the total number of positive finding on 2D of Nasal bone fractures is 29, of which, 27 (93%) are classified as positive by 3D of Nasal bone fractures and 2 (7%) are classified negative by the same. Of the negatives as per 2D of

Nasal bone fractures, all of them are classified as negatives by 3D of Nasal bone fractures also. The measurement of agreement kappa = 0.799 ($p < 0.001$).

For right zygomaticomaxillary fractures the total number of positive finding on 2D of Right Zygomaticomaxillary buttress is 27, of which, 25 (93%) are classified as positive by 3D of Right Zygomaticomaxillary buttress and 2 (7%) are classified negative by the same. Of the negatives as per 2D of Right Zygomaticomaxillary buttress , all of them are classified as negatives by 3D of Right Zygomaticomaxillary buttress also. The measurement of agreement kappa = 0.837 ($p < 0.001$).

For left zygomaticmaxillary fractures the total number of positive finding on 2D of Left Zygomaticomaxillary buttress is 31, of which, 29 (93.5%) are classified as positive by 3D of Left Zygomaticomaxillary buttress and 2 (7.5%) are classified negative by the same. Of the negatives as per 2D of Left Zygomaticomaxillary buttress, all of them are classified as negatives by 3D of Left Zygomaticomaxillary buttress also. The measurement of agreement kappa = 0.719 ($p < 0.001$).

For right nasomaxillary fractures the total number of positive finding on 2D of Right Nasomaxillary buttress is 26, of which, 25 (96%) are classified as positive by 3D of Right Nasomaxillary buttress and 1 (4%) are classified negative by the same. Of the negatives as per 2D of Right Nasomaxillary buttress , all of them are classified as negatives by 3D of Right Nasomaxillary buttress also. The measurement of agreement kappa = 0.922 ($p < 0.001$).

For left nasomaxillary fractures the total number of positive finding on 2D of Left Nasomaxillary buttress is 28, of which, 27 (96%) are classified as positive by 3D of Left

Nasomaxillary buttress and 1 (4%) are classified negative by the same. Of the negatives as per 2D of Left Nasomaxillary buttress , all of them are classified as negatives by 3D of Left Nasomaxillary buttress also. The measurement of agreement kappa = 0.905 ($p < 0.001$).

For right infraorbital rim fractures the total number of positive finding on 2D of Right Infraorbital rim is 25, of which, 24 (96%) are classified as positive by 3D of Right Infraorbital fractures and 1 (4%) are classified negative by the same. Of the negatives as per 2D of Right Infraorbital rim , all of them are classified as negatives by 3D of Right Infraorbital fractures also. The measurement of agreement kappa = 0.927 ($p < 0.001$).

For left infraorbital rim fractures the total number of positive finding on 2D of Left Infraorbital rim is 29, of which, all are classified as positive by 3D of Left Infraorbital rim. Of the negatives as per 2D of Left Infraorbital rim , all of them are classified as negatives by 3D of Left Infraorbital rim also. The measurement of agreement kappa = 1.00 ($p < 0.001$).

For mandibular fractures the total number of positive finding on 2D of Mandible fractures is 14, of which, 13 (93%) are classified as positive by 3D of Mandible fractures and 1 (7%) are classified negative by the same. Of the negatives as per 2D of Mandible fractures, all of them are classified as negatives by 3D of Mandible fractures also. The measurement of agreement kappa = 0.939 ($p < 0.001$).

In the diagnosis of Le fort fractures using 2D and 3D CT images the most common fractures was a combination of Lefort I and Lefort II in both 2D and 3D with a more true positives diagnosed in 2D thereby meaning greater sensitivity and more false positive in 3D thereby meaning a higher level of sensitivity.

Diagnostic Difficulties.

1. 2D CT gives a better idea about soft tissue injuries as compared to 3D CT especially in blow out fracture of the orbit and this can alter the management of reconstruction of the floor by either using alloplastic material or costochondral grafts.

2. Undisplaced fractures are better picked up by 2D CT as compared to by 3D CT.

3. The crucial importance of 3D CT over 2D CT is seen in comminuted and displaced fractures.

4. “Pseudoforamina” ie artifactual defects in the thin bones commonly involving the inferior and medial orbital walls may create improper readings of 3D CT.

Another major issue in 3D CT is the cost involved which amounts to Rs.3900/- whereas a conventional axial and coronal CT cost only Rs.1500/-. This means the financial burden that the patient has to bear is an additional cost of about Rs.2400/-.

Although the basic surgical treatment in any Le Fort fracture is to obtain total fixation with miniplates and screws of all fractures along with obtaining occlusion through inter-maxillary fixation, this may not often be the case due to various factors including patient compliance. In such situations then the less than ideal treatment would be to reduce and fix all the horizontal and vertical buttress of the facial bones. Since this is usually done at our centre and since the 3D CT does not provide any additional information it is best to avoid the additional 3D image reformatting and can be imperative to state that 3D CT does not generally change the management plan. However in certain situation like mentioned above, if there are comminuted fracture of the zygomatic complex and medial wall of the orbit with grossly displaced fracture segments then a 3D reformatted image may provide much more information and help the operating surgeon with sufficient information which may help in treatment planning.

SUMMARY

This is a prospective study of 34 cases from August 2006 to August 2008 who under presented to the Department of Plastic and Reconstructive Surgery. All the patients were initially diagnosed to have Le fort fractures clinically and then subjected to 2D and 3D reformatting. The data was statistically analyzed.

Knowledge of the regions of the face and buttresses knowledge of the types of facial injuries frequently encountered simplifies the diagnostic task. The indications for CT are mainly for accurate diagnosis of these injuries.

The availability of 3D CT reformatting of 2D CT images infrequently changed the interpretation of 2D images of the facial bone fractures. The addition of 3D CT images did not improve the accuracy of the interpretation. The frequency of changes and interpretation correlated inversely with the experience of the observer. It was also seen the basic surgical treatment plan did not vary with the addition of the 3D CT images.

There are higher costs involved in using 3D as compared to using the conventional 2D axial and coronal views when diagnosing a facial bone fracture. It may be difficult to decide prior to CT which patients require 3D reformatting also. However the best option is to proceed with a 2D CT and then if required a 3D for certain regions where details of the bony derangements may be better picked up like medial wall of the orbit and zygoma fractures.

CONCLUSION

This study of 34 cases of Le Fort fractures has shown that 2D CT scanning has provided valuable information regarding the extent of fractures as well as various details regarding each fracture displacement.

The additional 3D CT reformatting that was done in each of these cases has also picked up large number of fractures. It is however evident that none of the fractures that were picked up by 3D CT reformatting were missed out by the 2D thereby giving a clear indication that 2D CT specificity was much greater.

As surgical repair of Le Fort fractures is governed by the principles of fracture reduction of facial pillars and since all these fractures can be picked up easily by 2D CT it is unnecessary to proceed with a 3D CT reformatting as this additional investigation does not change the management plan.

3D CT gives a more detailed idea to surgeon regarding spacial orientation of the various fracture sites but does not change the management plan.

Taking into consideration the vast difference if its cost it is at present an unnecessary investigation.

In the future as technology improves and costs of these investigations come down and assessment time becomes less 3D CT reformatting may become an integral part of diagnosing all Le Fort fractures but until that date it 2D remains the best investigation for interpreting simple facial bone fractures and those fractures that are not grossly comminuted.

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PROFORMA

NAME	-
AGE	-
SEX	-
RELIGION	-
OCCUPATION	-
DATE OF ADMISSION	-
DATE OF SURGERY	-
DATE OF DISCHARGE	-
HISTORY	- Road Traffic Accident.
	- Assault.
FINDINGS	- Supraorbital Step Deformity.
	- Infraorbital Step Deformity.
	- Nasal Bone Crepitus.
	- Loss of Sensation over Ala.
	- Palatal Mobility.
ASSOCIATED INJURIES	-

INVESTIGATIONS	- Routine Blood
	- Routine Urine
	- Radiology = X-Ray. (Water's view)
	2D CT
	3D CT
PROVISION CLINICAL DIAGNOSIS	-
TREATMENT GIVEN	-
POST OPERATIVE PERIOD	-
POST – OP COMPLICATION	-
REVISION SURGERY IF ANY	-

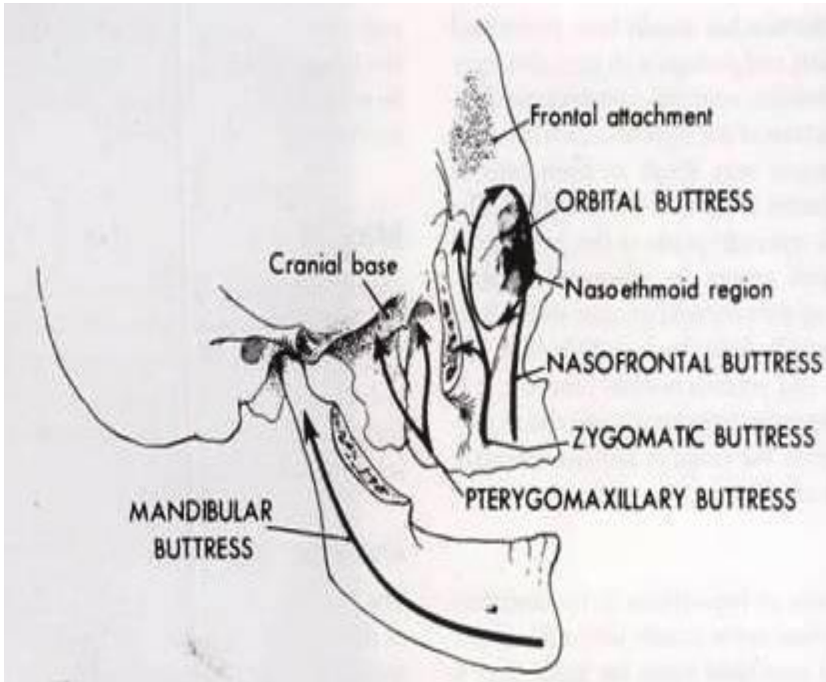


Fig 1.4 Picture depicting the various horizontal and vertical buttresses.

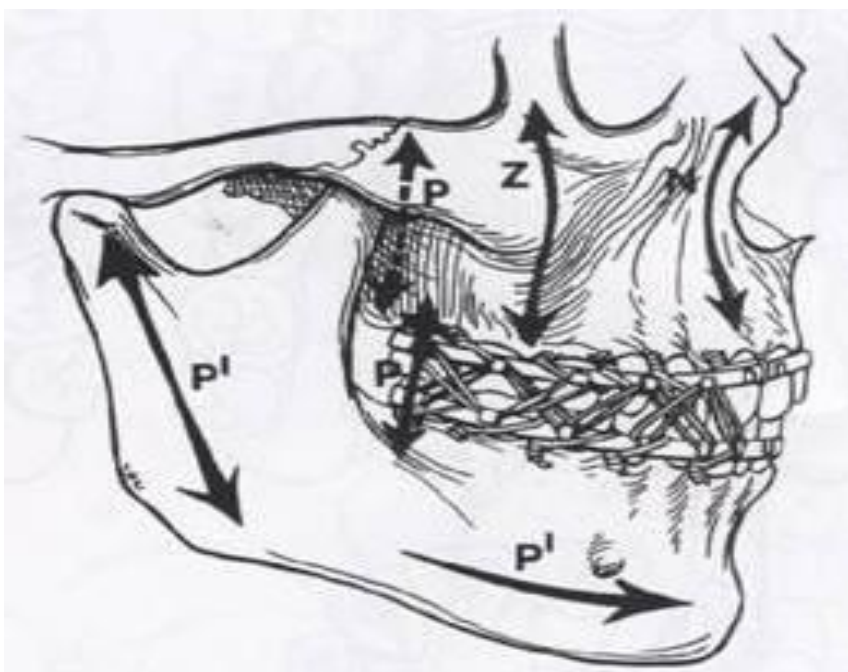


Fig 1.4A. Vertical and Horizontal buttress

Fig 1.5 Le Fort I fracture line.

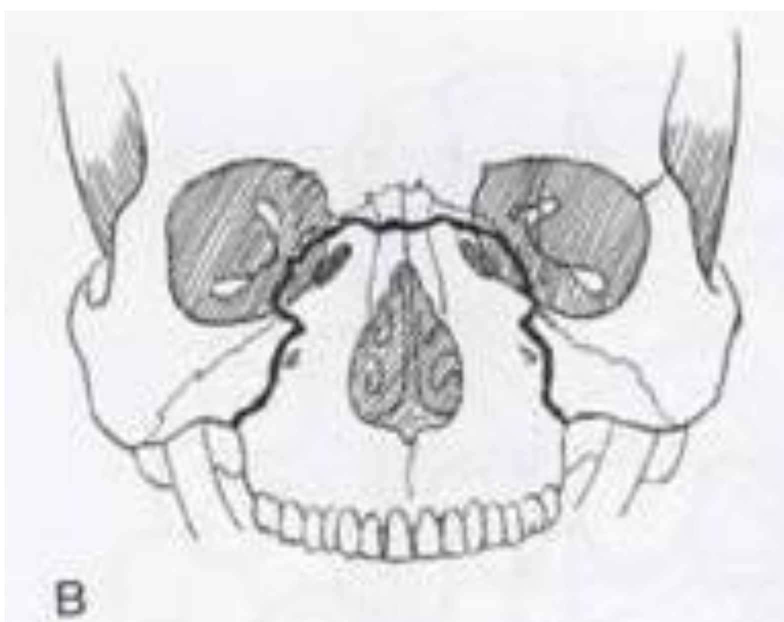


Fig 1.6 Le Fort II fracture line

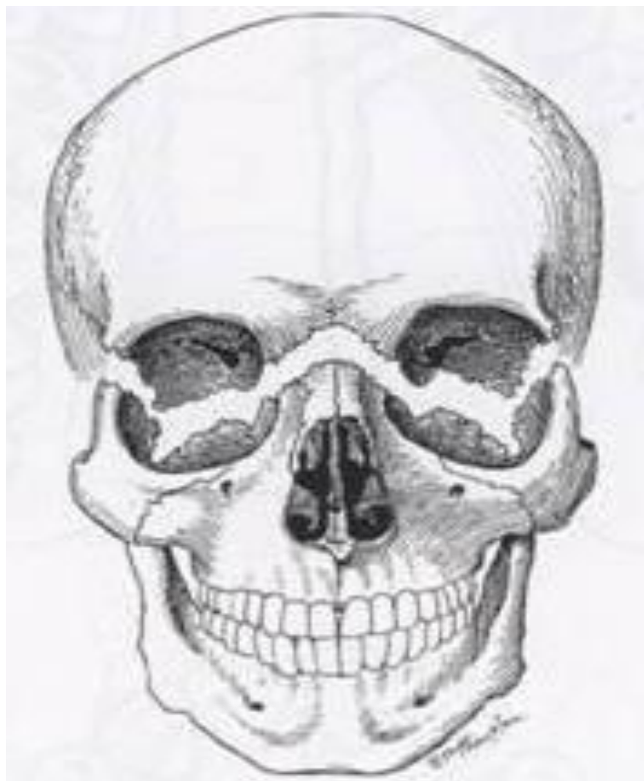


Fig 1.7 Le Fort III fracture line with facial dysjunction

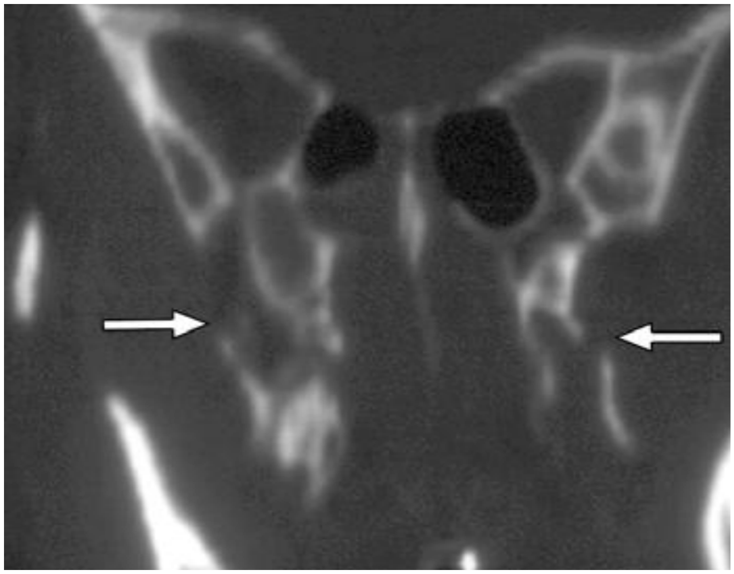
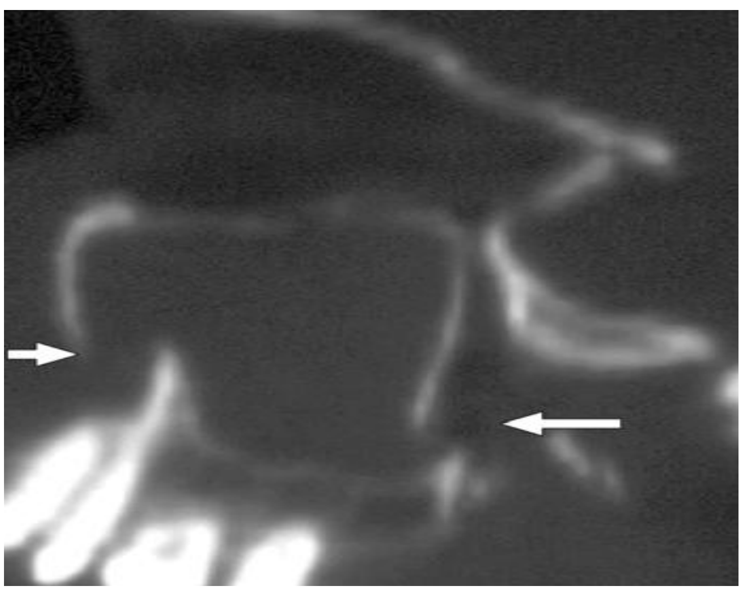
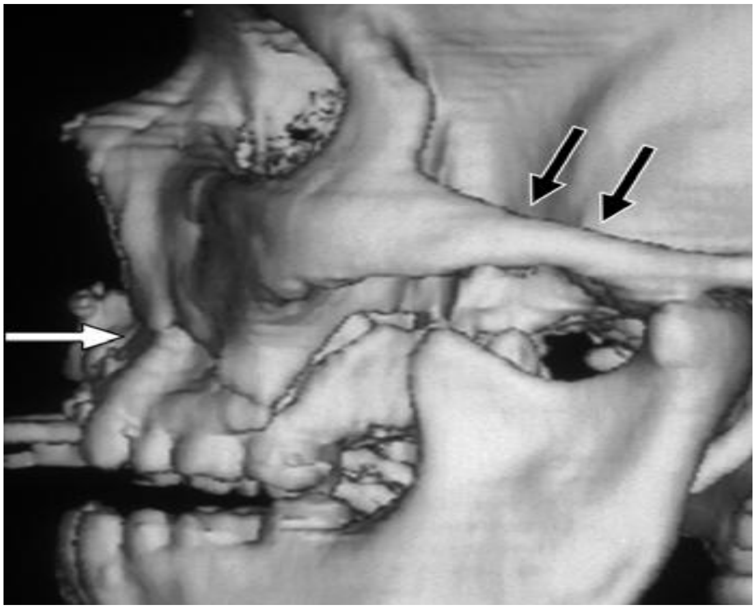


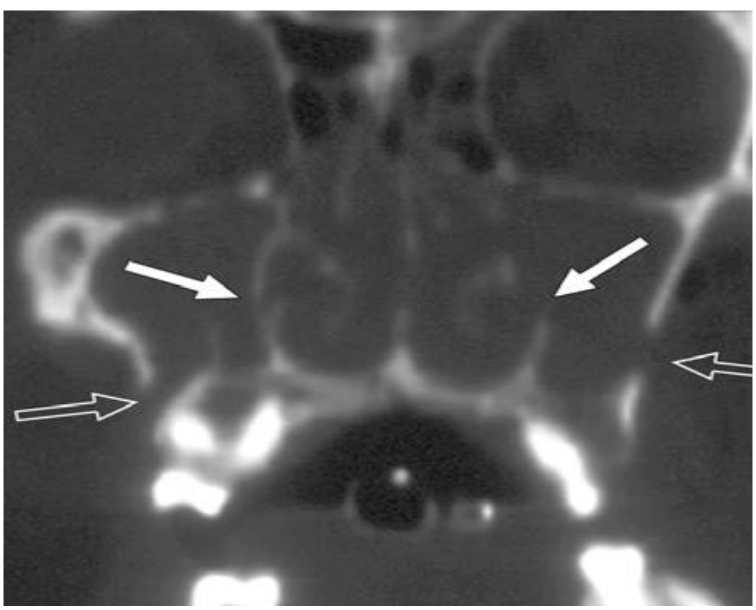
Fig 1.5 A, Coronal CT image shows bilateral fractures of pterygoid processes (*arrows*).



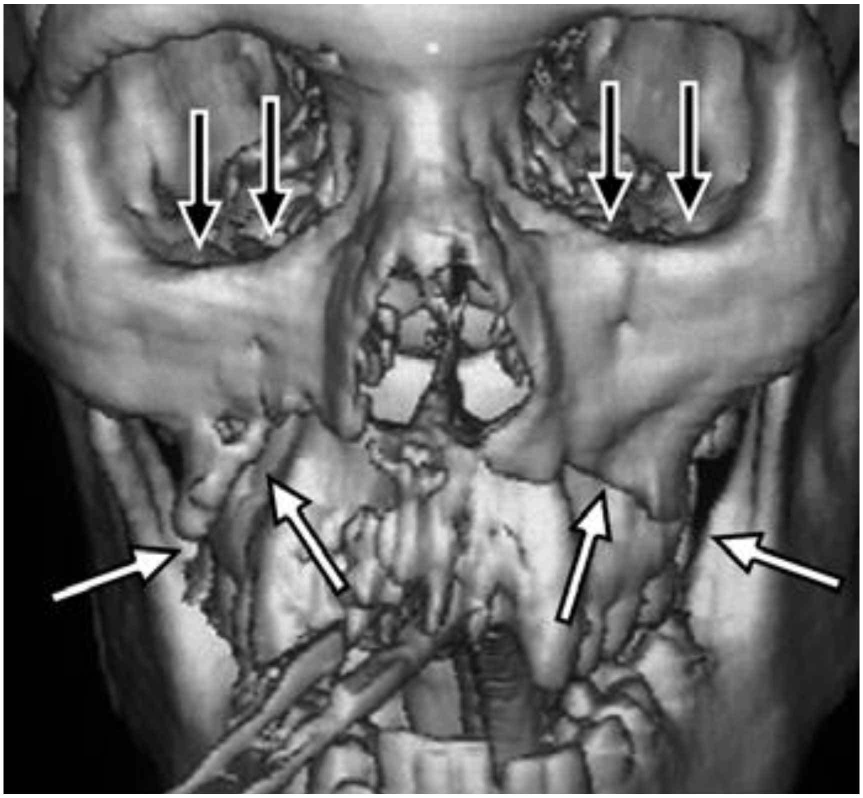
B, Sagittal CT image shows fractures (*arrows*) in horizontal plane of walls of maxillary sinus.



C, Three-dimensional image in lateral projection shows fracture of anterolateral margin of nasal fossa (*white arrow*), which indicates that Le Fort I fracture is present. Zygomatic arch (*black arrows*) is intact, thus excluding Le Fort III fracture



D, Coronal CT image shows fractures of lateral margins of nasal fossa (*solid arrows*) and lateral wall of maxillary sinuses (*open arrows*).



E, Three-dimensional image in frontal projection shows intact inferior orbital rims (*black arrows*), thus excluding Le Fort II fracture. Horizontally oriented fractures across maxillary sinuses and nasal fossa (*white arrows*) are seen.

Multislice CT machine

Right Le Fort Fractures Diagnosed by 2D CT

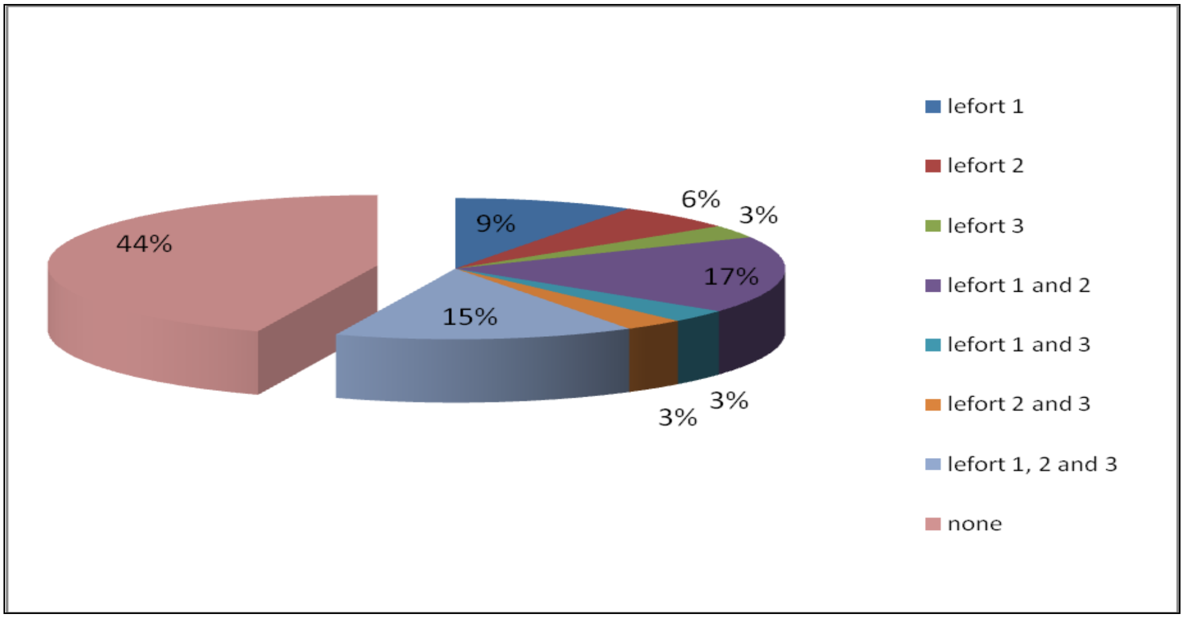


Figure 12

Right Le Fort Fractures Diagnosed by 3D CT

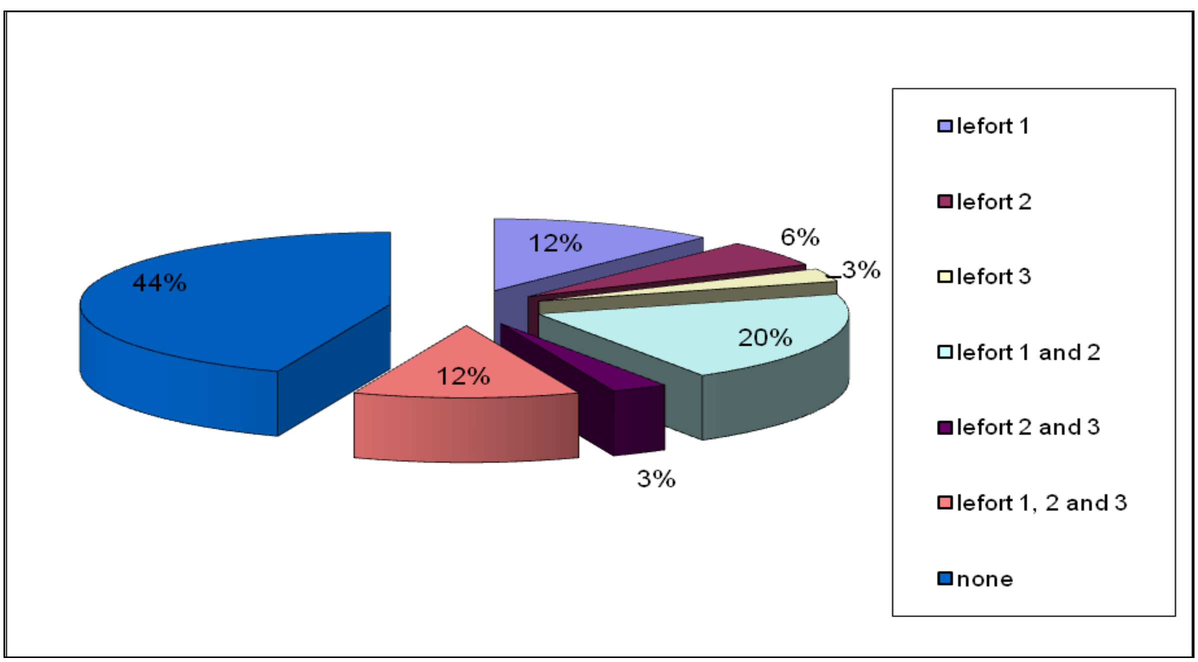


Figure 13

Left Le Fort Fractures Diagnosed by 2D CT

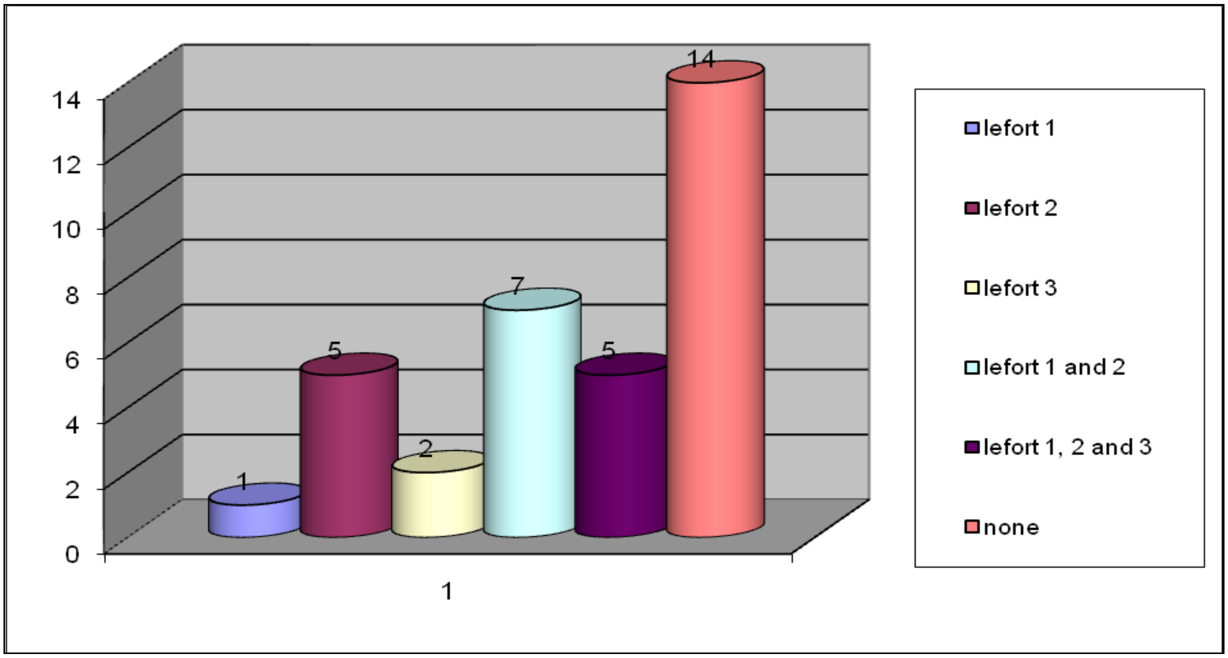


Figure 14

Left Le Fort Fractures Diagnosed 3D CT

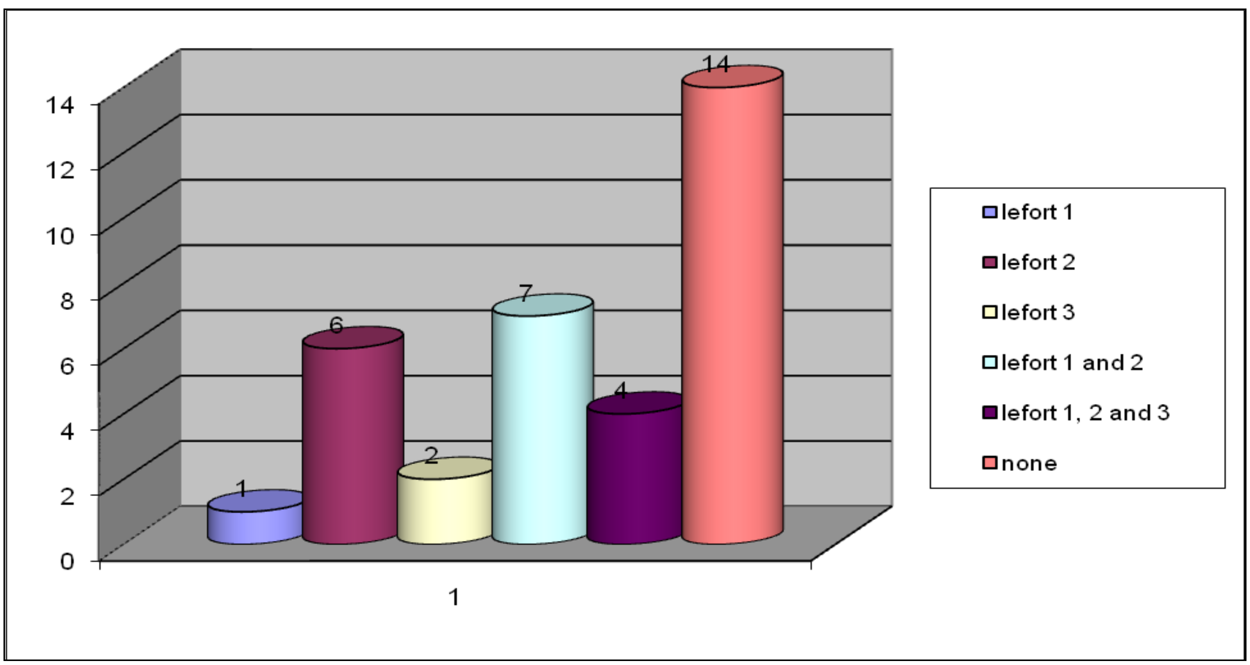


Figure 15

Bilateral Le Fort Fractures Diagnosed by 2D CT

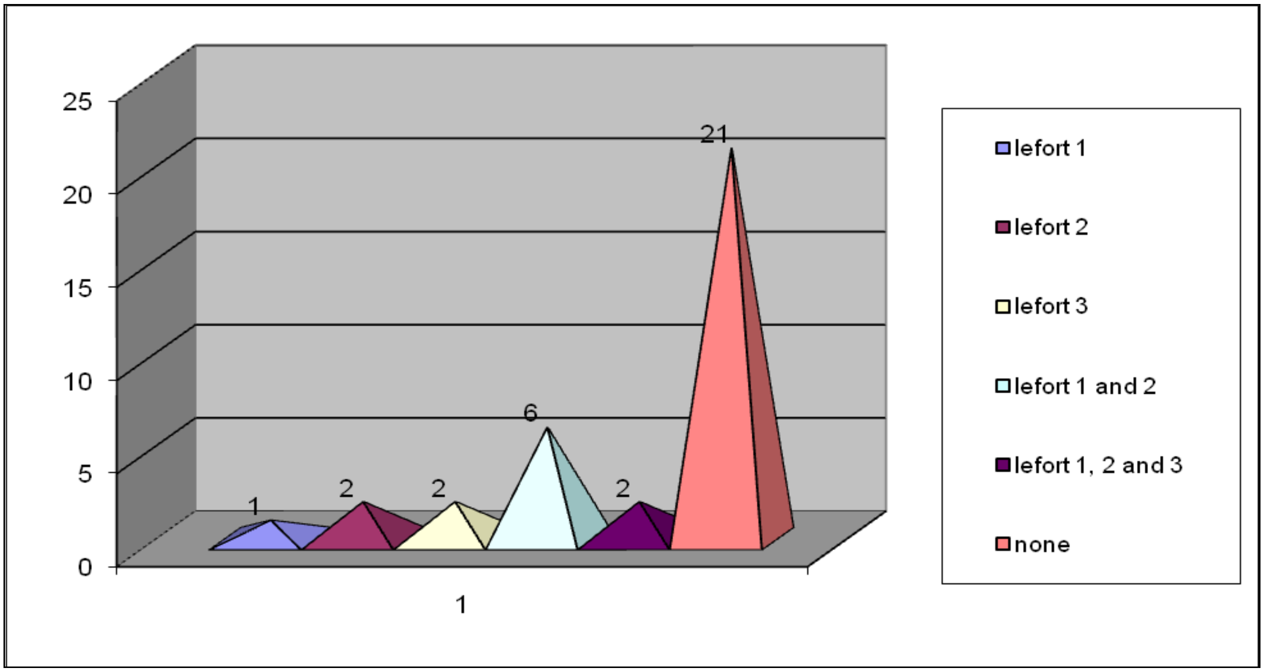


Figure 16

Bilateral Le Fort Fractures Diagnosed by 3D CT

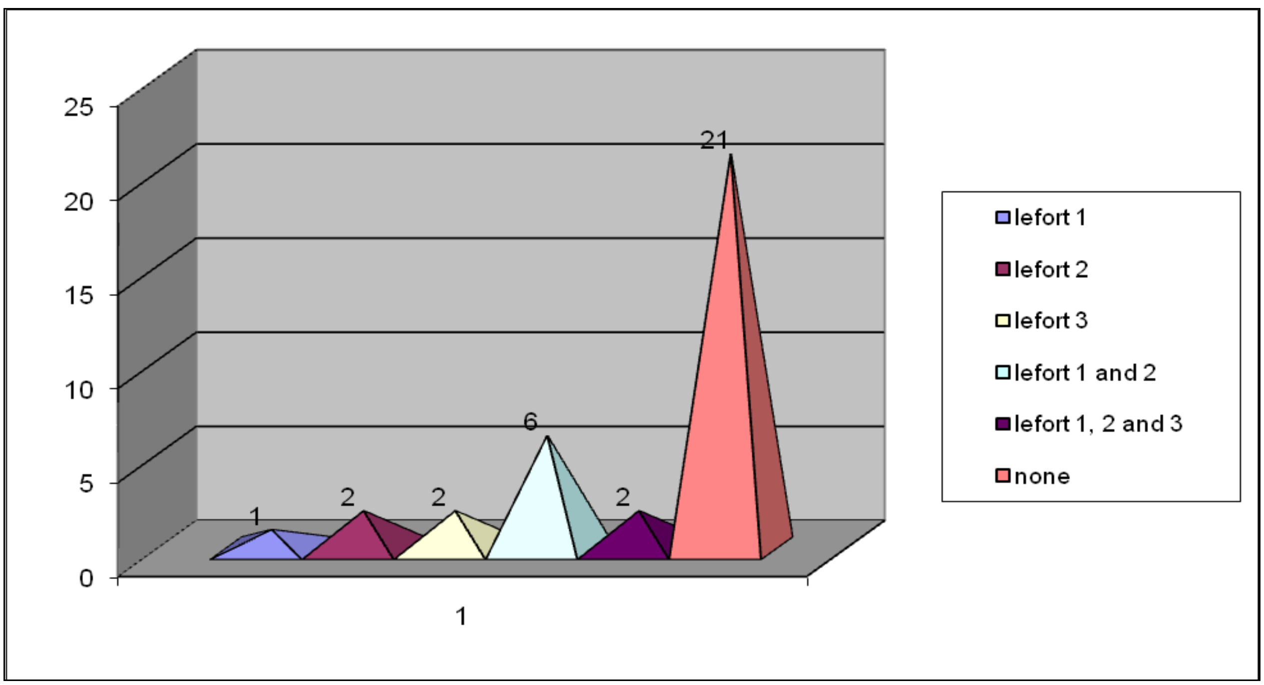
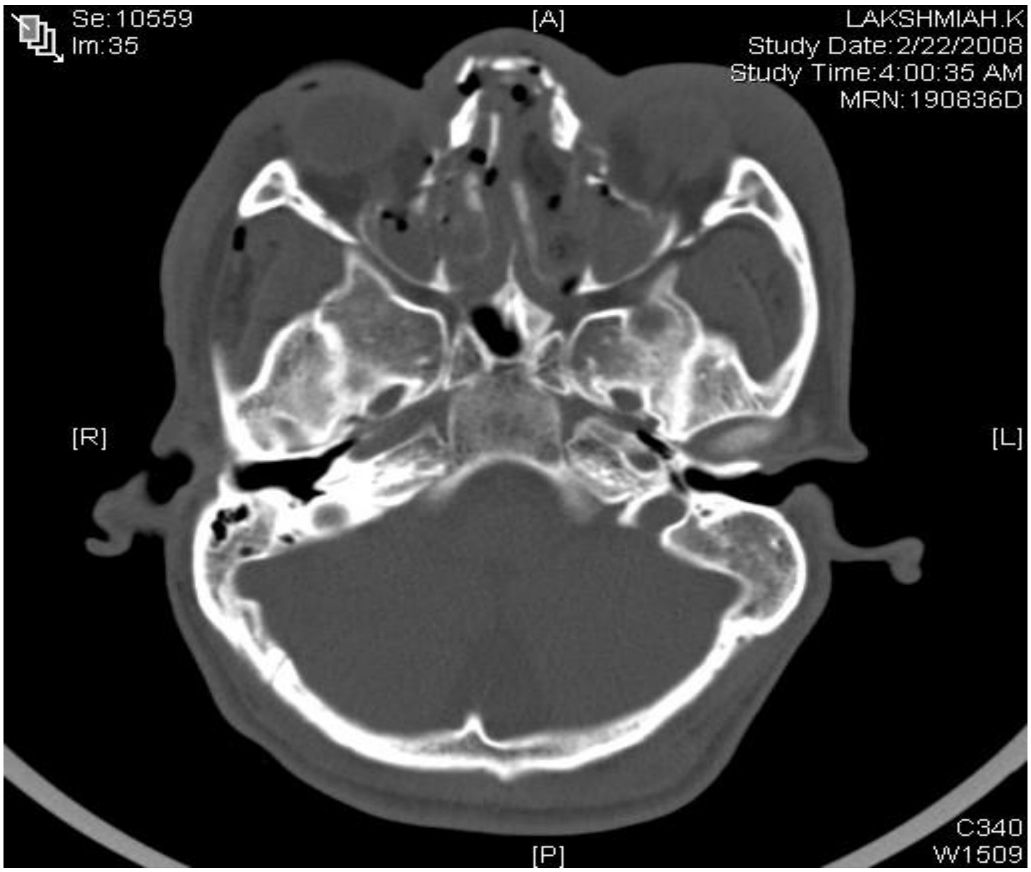
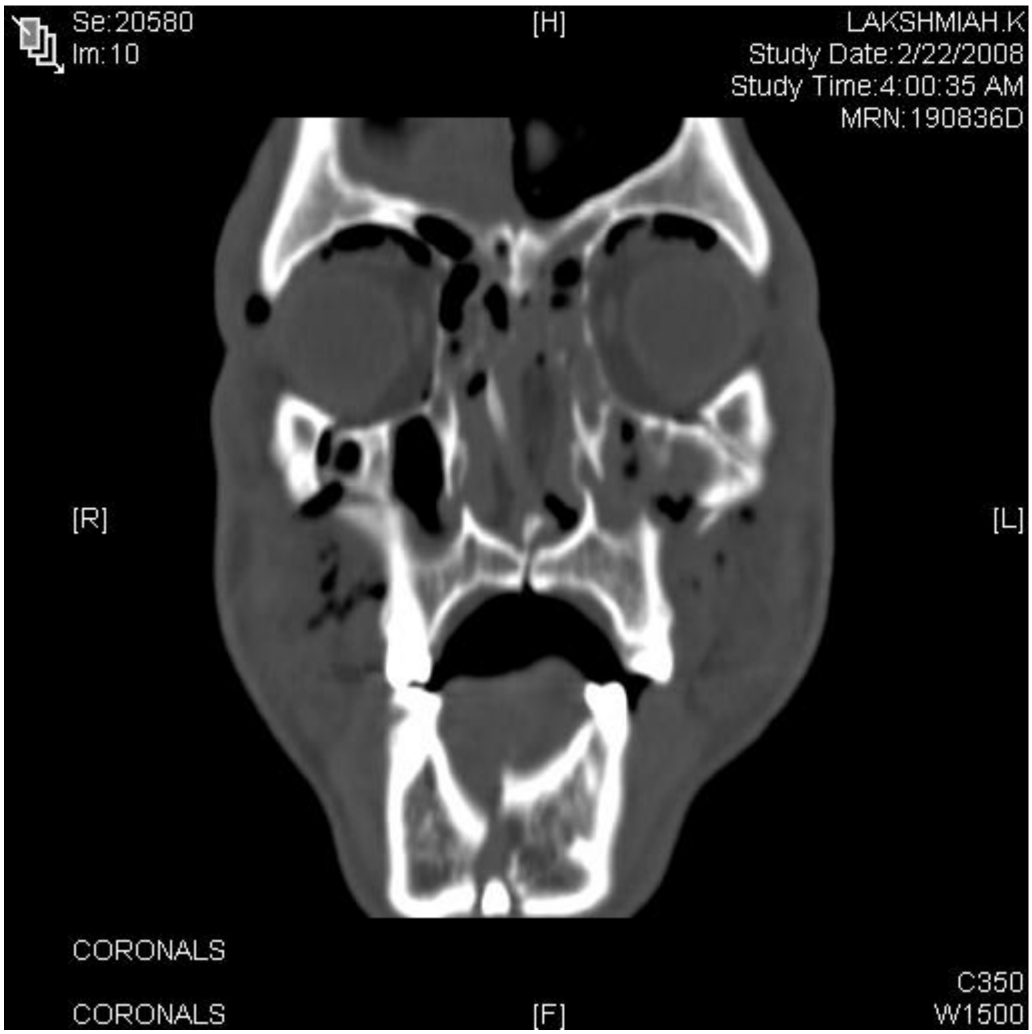


Figure 17

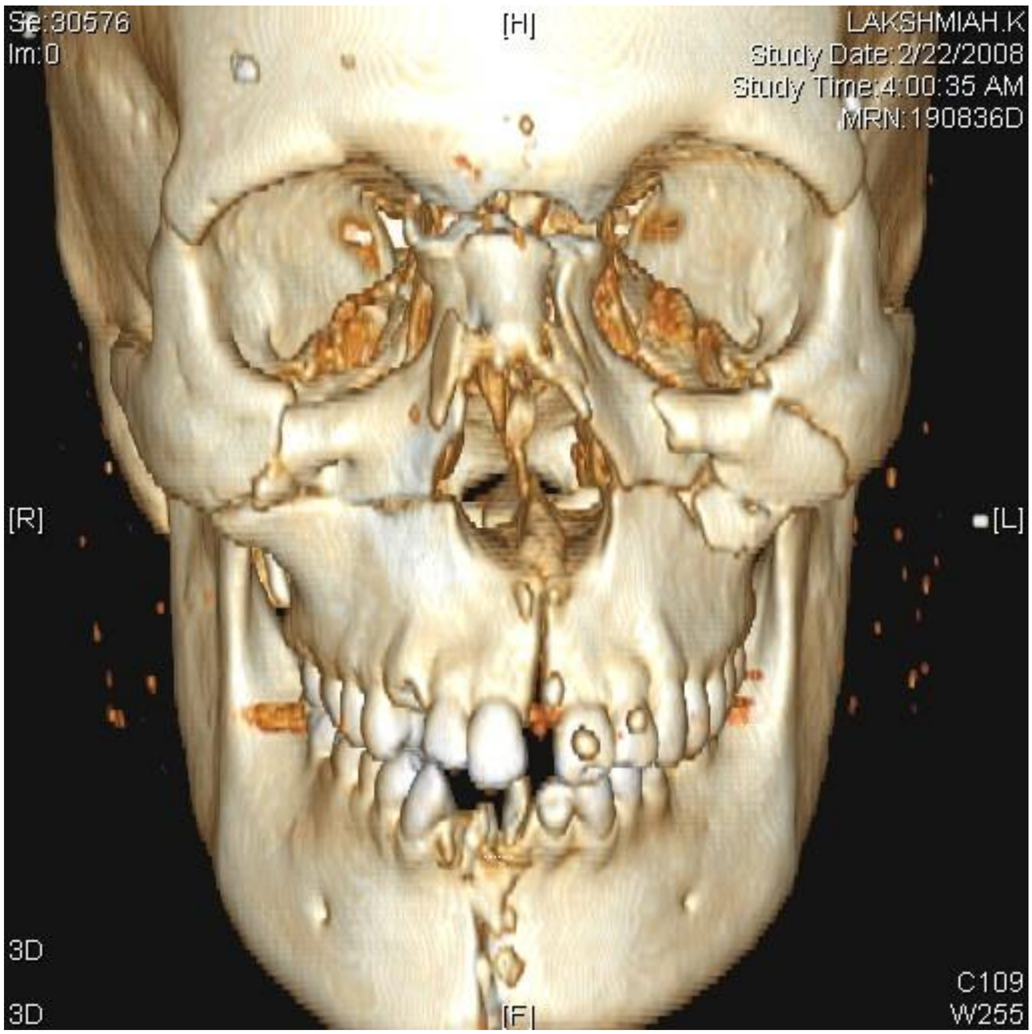
2D AXIAL IMAGE



2D CORONAL IMAGE



3D IMAGE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